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Comparison and Applications of DPV-2000 and Accuraspray-g3 Diagnostic Systems

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Comparative in-flight measurements of particles plasma sprayed by F4 and Triplex II guns were carried out using the diagnostic systems DPV-2000 and Accuraspray-g3. The comparison of mean particle velocities and temperatures as well as intensity profiles of the plume show a good agreement confirming their accuracy. However, the varying operating principles especially the deceased dimensions of the measurement volumes have to be considered carefully when evaluating the results. Furthermore, some applications of the diagnostic systems DPV-2000 and Accuraspray-g3 are shown. Finally some application limits, which were identified for certain powder compositions at higher plasma power levels will be discussed.

Keywords diagnostics, plasma spraying, process monitoring, process optimization

1. Introduction

Growing demands on the quality of plasma sprayed coatings require reliable methods to monitor and optimize the spraying processes. As the coating microstructures are predominantly dependent on the characteristics of the particles the importance of in-flight diagnostics is increasing (Ref 1-6). In the first part of this paper comparative measurements using the DPV-2000 and the Accuraspray-g3 diagnostic systems give information about the applicability and the accuracy of particle velocity, temperature, and intensity profile measurements. Here the diagnostic system themselves are also introduced. The second part focuses on some different practical applications of both the systems to demonstrate the benefits of particle diagnostics and gives some advice for practical use.

2. Applied Particle Diagnostic Systems

The atmospheric plasma spray facilities at the Institute of Energy Research, Juelich Research Centre, Germany, are equipped with two particle diagnostic systems, the well-established DPV-2000 (Fig. 1) and the newer Accuraspray-g3 (Fig. 2) (Ref 7-10). Both were developed by TECNAR Automation Ltd., St-Bruno, Qc, Canada.

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2.1 DPV-2000 Diagnostic System

The DPV-2000 enables to measure particle velocities, temperatures, and diameters. The velocity is obtained by measuring the time between the two signals which are triggered by a radiating particle passing the two-slit mask of the optoelectronic sensor head. In conjunction with the distance of the slits and the magnification factor of the lens the velocity can be calculated. The temperature is acquired by two-color pyrometry, i.e., by calculating the ratio of the energy radiated at two different wave lengths assuming that the particles are gray body emitters with the same emissivity at both color bands. The diameter is obtained from the radiation energy emitted at one wavelength assuming that the melted particles are spherical or close to be. Since it is necessary to know the real emissivity of the particle a prior calibration by means of a powder with known diameter distribution has to be carried out. As the measurement volume is relatively small (<1 mm^3) the data is collected for individual particles and can subsequently be analyzed statistically. A certain measurement time is necessary to support the mean and standard deviations by a sufficient number of individual particle data.

2.2 Accuraspray-g3 Diagnostic System

Contrary to the DPV-2000 the Accuraspray-g3 diagnostic system provides ensemble average data representing the particle characteristics in a measurement volume of approx. Ø 3×25 mm^2. Particle velocities are obtained from cross-correlation of signals which are recorded at two closely spaced locations. The temperatures again are determined by two-color pyrometry. As ensemble methods are used it is neither possible to evaluate the distribution and standard deviations of particle velocities and temperatures nor to estimate the particle diameters by the Accuraspray-g3. The other component of this system consists of a CCD camera enabling the analysis of the plume appearance (position, width, distribution, intensity) along a line in spray distance perpendicular to the particle jet.

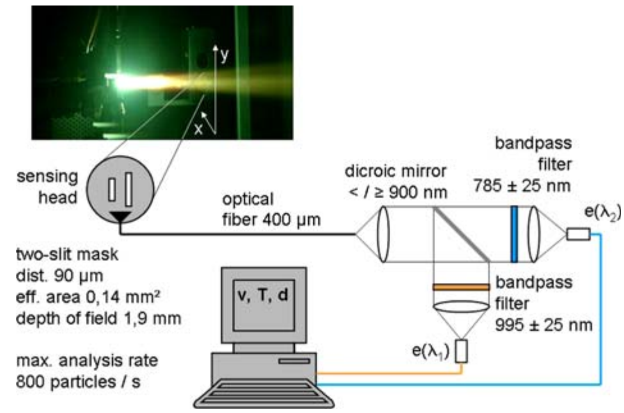

Fig. 1 Operation principle of the DPV-2000 diagnostic system

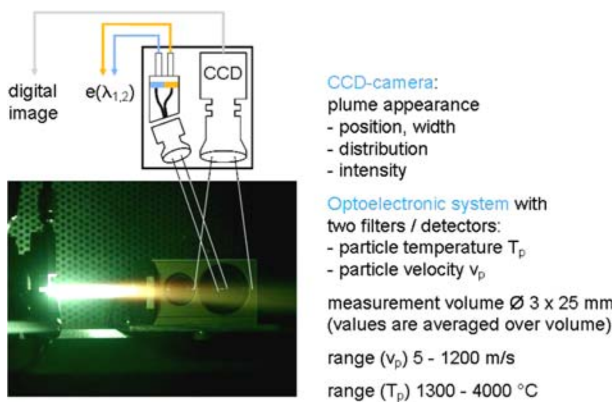

Fig. 2 Operation principle of the diagnostic system Accuraspray-g3

	DPV-2000	Accuraspray-g3
meas. volume	1,4 mm² x 1,9 mm	Ø 3 mm x 25 mm
analysis	single particle method, statistics	ensemble method, average values
v-meas.ment	time-of-flight, peak-to-peak	correlation of time-delayed signals
T-meas.ment	two-color pyrometry	two-color pyrometry
d-meas.ment	emission	-
intensity	trigger/time	digital imaging

Fig. 3 Main features in comparison of particle diagnostic systems DPV-2000 and Accuraspray-g3

Figure 3 summarizes the main features of both diagnostic systems.

3. Comparison Measurements

3.1 Experimental

Comparative measurements of *particle velocity and temperature* were carried out on a Multicoat facility

Table 1 Spraying parameters for comparative measurements of particle characteristics

	F4	Triplex II
Current	660 A	500 A
Plasma gas	40 slpm Ar, 10 slpm H_2	40 slpm Ar, 10 slpm He
Carrier gas	3,5 slpm Ar	1,6 slpm Ar
Powder feed disk	5%	5%/10%/20%
Stand-off distance	100 mm	175 mm

Table 2 Spraying parameters for comparative measurements of intensity profiles

	Triplex II
Current	520 A
Plasma gas	50 slpm Ar, 4 slpm He
Carrier gas	1,6 slpm Ar
Powder feed disk	10%
Stand-off distance	100 mm

(Sulzer Metco, Wohlen, Switzerland) when atmospheric plasma spraying with both a single cathode F4 and a multi cathode Triplex II gun mounted on a six-axis robot. The powder was 8% Yttria stabilized Zirconia Sulzer Metco 204NS. The particle diameter distribution was $d_{10} = 25$ µm, $d_{50} = 57$ µm, $d_{90} = 101$ µm, the morphology was spheroidal resulting from the manufacturer's proprietary HOSP process (Sulzer Metco Europe GmbH, Hattersheim, Germany). The spray parameters are listed in Table 1, for the Triplex II gun three settings of the powder feed disk were used.

Comparative measurements of *plume intensity profiles* were carried out on a Sulzer Metco Multicoat facility when atmospheric plasma spraying with a multi cathode Triplex II gun mounted on a six-axis robot. The powder was 8% Yttria stabilized Zirconia Praxair ZRO-196 (Praxair Surface Technologies Inc., Indianapolis, USA). The particle diameter distribution was $d_{10} = 5$ µm, $d_{50} = 33$ µm, $d_{90} = 59$ µm, the morphology is spherical densified. The use of another powder for the intensity measurements than for the velocity and temperature measurements is due to the different applications the measurements originated from. However, as these are two independent investigations this is not essential. Three modes of powder injection were applied, injection from above (inj. A), injection from bottom left (inj. C) and the combination of both (inj. A + C). The designations of left and right refer to the viewing direction towards the gun. The further process parameters are listed in Table 2.

3.2 Results

The *DPV-2000 measurements of particle velocities and temperatures* were operated on a 7×7 point grid in a plane normal to the gun axis in stand-off distance. For the F4 gun the grid was dimensioned 12×12 mm^2 and for the Triplex II gun 24×24 mm^2, respectively. The measurement grid for the Triplex II gun had to be enlarged compared to the grid used for the F4 gun, because at the Triplex II gun the particle flux was found to be not such concentrated as at the F4. So an enlargement was necessary to cover the plume cross-section of the Triplex II sufficiently. However, for the F4 gun an equally large measurement grid is not reasonable because at the edges of the grid there are only very few particles. Measurement time on each grid point was 5 s, which allows for sufficient support of the mean and standard deviations by some hundred single particle data at least in the central grid area. Before measuring the gun was centered by the DPV-2000 autocenter function so that the central point of the measurement grid ($x = 0$ mm, $y = 0$ mm) refers to the maximum intensity of the particle jet. Figure 4 shows the DPV-2000 measured results for the F4 gun and Fig. 5 for the Triplex II gun (example for powder feed disk 5%). The standard deviations of the velocities at the distinct grid points averaged 48 m/s for the F4 gun and 35 m/s for the Triplex II, respectively. The corresponding values for the temperatures were 162 and 135 K.

The *Accuraspray-g3 measurement of particle velocities and temperatures* was carried out also in the intensity maximum of the particle jet. The intensity profile which is determined by the CCD camera component of the system makes it easy to adjust the gun. As pointed out in the description of the systems the Accuraspray-g3 is based on an ensemble method resulting averaged values. Single particle data as obtained by the DPV-2000 are not accessible. Hence, using the Accuraspray-g3 comparable standard deviations cannot be specified.

When comparing the measured particle velocities and temperatures with the ones delivered by the DPV-2000 system it has to be considered that the Accuraspray-g3 data are average values representing a wide particle fraction in a comparatively large measurement volume. Regarding the length of the Accuraspray-g3 measurement volume of 25 mm it is obvious that it covers the entire width of the applied DPV-2000 measurement grid. As the Accuraspray-g3 system averages particle data on the whole measurement volume to one single representing value, hereby a weighting by the particle frequency is implied. The same procedure has to be done with the data measured by the DPV-2000 to ensure comparability. Thus, the local mean values of the particle data at each DPV-2000 grid point which is contained by the Accuraspray-g3 measurement volume must be weighted by the local particle flow rates to achieve one global mean value. Figure 6 shows the comparison of the results. In each case the left

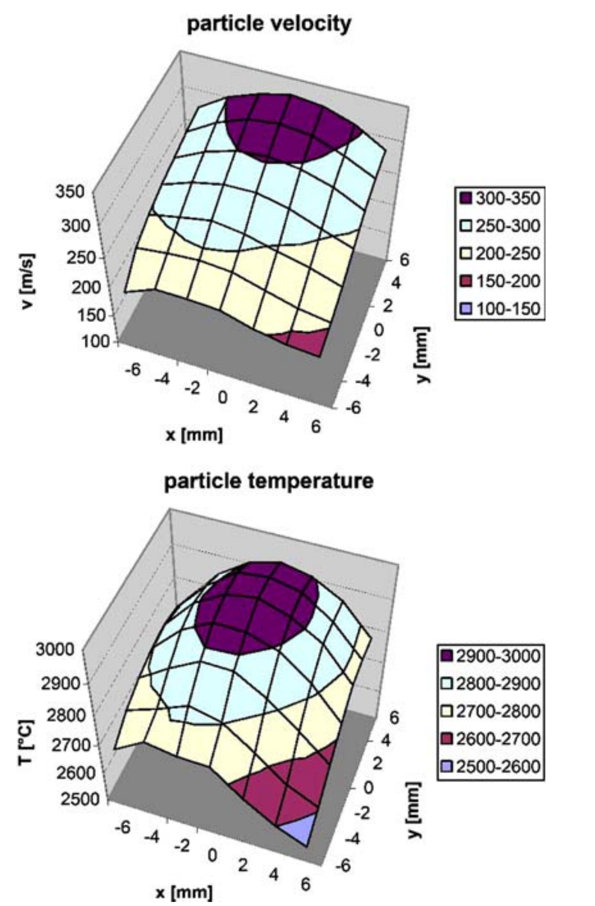

Fig. 4 DPV-2000 measured distribution of particle velocities, temperature, flow rate and diameter when using the F4 gun

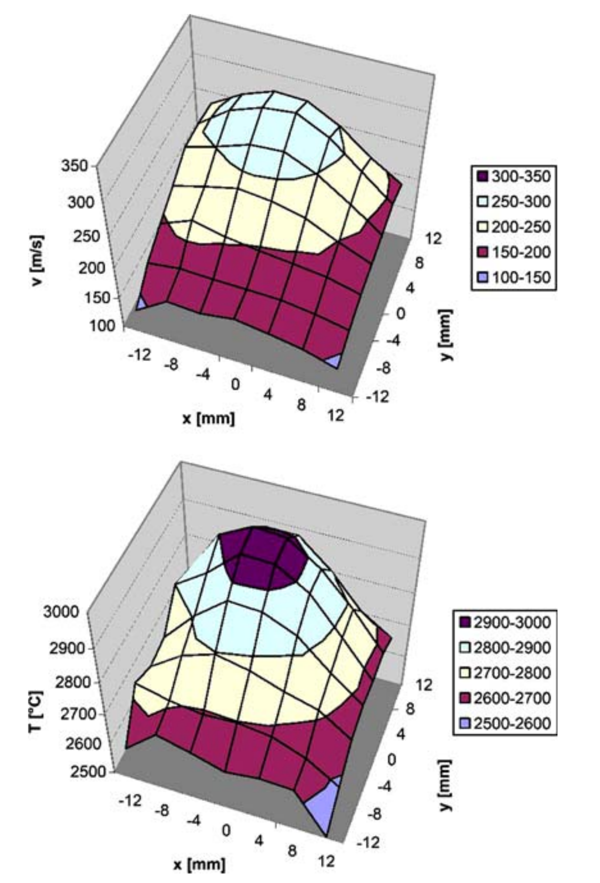

Fig. 5 DPV-2000 measured distribution of particle velocities, temperature, flow rate, and diameter when using the Triplex II gun (powder feed disk 5%, enlarged measurement grid vs. F4)

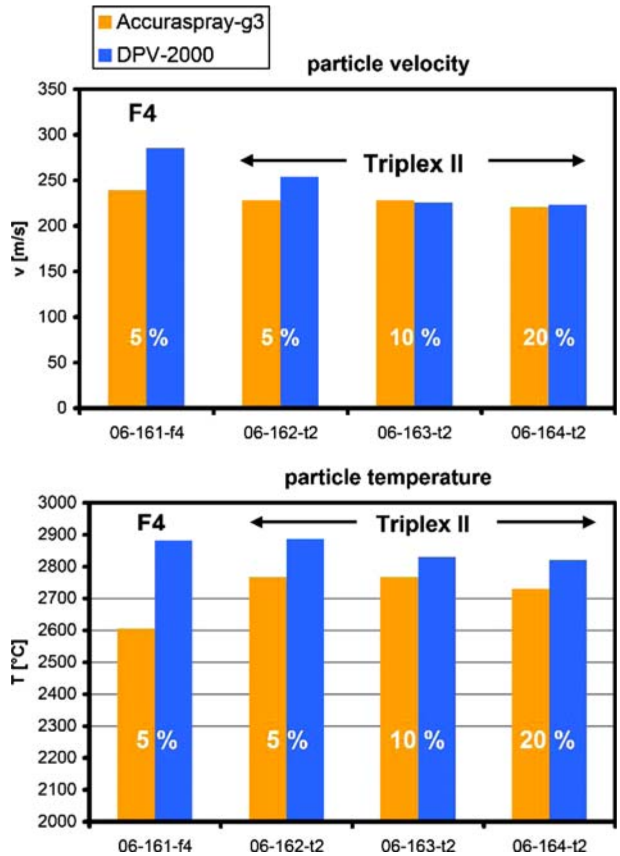

Fig. 6 Comparison of mean particle velocity and temperature based on DPV-2000 and Accuraspray-g3 measurements using the F4 and the Triplex II gun; percentage values refer to the rotation speeds of the powder feed disk

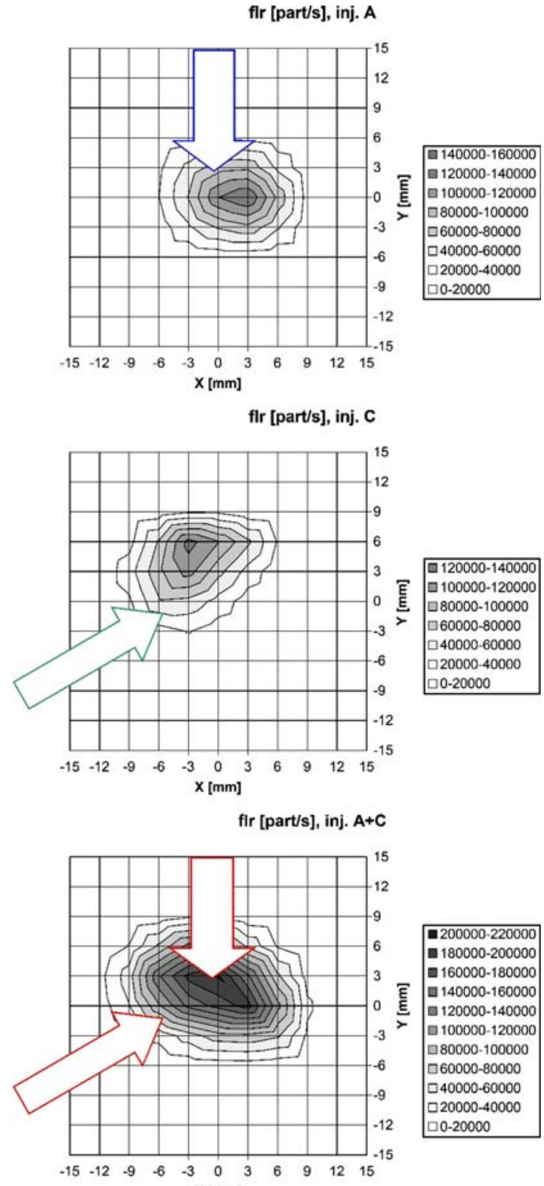

Fig. 7 DPV-2000 measured distributions of particle flow rates for three powder injection modes

ones of the column pairs represent the Accuraspray-g3 achievements; the right ones depict the flux weighted and averaged DPV-2000 data. Comparisons are shown for one application of the F4 gun and three different powder feed rates applied to the Triplex II gun, depicted by the percentage values.

To obtain *intensity profiles from DPV-2000* measurements the particle flow rate was recorded on an 11×11 point measurement grid with side lengths of 30×30 mm^2 perpendicular to the gun axis and in spray distance. Measurement time on each grid point was 5 s, which allows for sufficient support of the mean and standard deviations by some hundred single particle data at least in the central grid area. The gun was centered so that the central point of the measurement grid ($x = 0$ mm, $y = 0$ mm) is the interception point of the grid plane and the geometrical gun axis. Figure 7 shows the measured flow rates. The projections of these two-dimensional distributions onto the x-axis and the y-axis, respectively, result in the horizontal and vertical intensity profiles of the powder jet in spray distance.

By means of the CCD camera component of the *Accuraspray-g3 intensity profiles* of the plume along a vertical line which complies with the y-axis of the DPV-2000 measurement plane were recorded. The units are arbitrary. In order to record a horizontal profile the six-axis robot was used to perform a 90° turn of the gun around its axis. In this position the y-axis of the Accuraspray-g3 on which the profile is recorded complies with the inverted x-axis of the DPV-2000 measurement plane. Thus also the horizontal intensity profiles measured with both the diagnostic systems can be compared. Figure 8 shows the results.

3.3 Discussion

The comparison of the *particle velocity and temperature* values shows the greatest differences for the F4 gun (−16% for the mean velocity and −10% for the mean

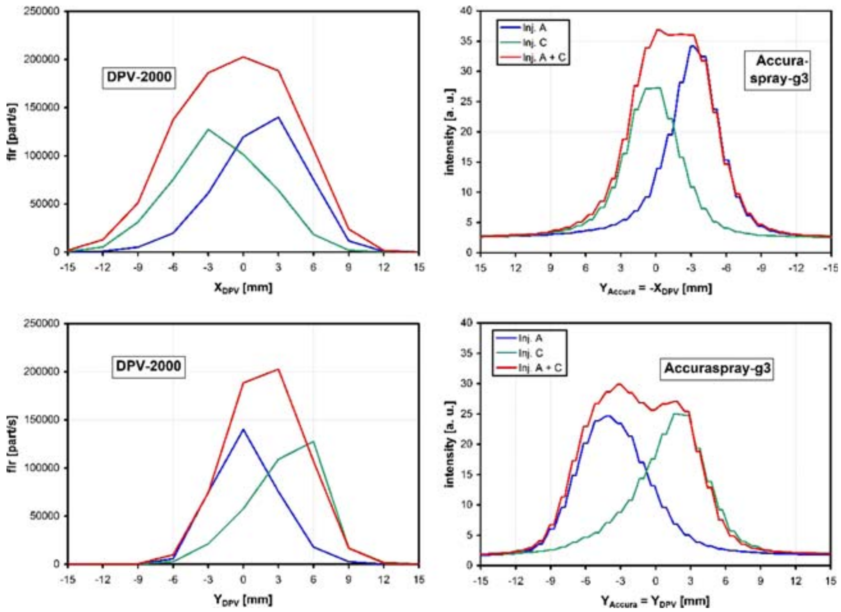

Fig. 8 Comparison of horizontal (top) and vertical (bottom) plume intensity profiles based on DPV-2000 and Accuraspray-g3 measurements

temperature). The reason is that a smaller measurement grid was used for the F4 gun. The Accuraspray-g3 measurement volume was obviously longer than the width of the measurement grid. Therefore, particles with low velocity and low temperature which are not covered by the DPV-2000 measurement were acquired at the margins of the Accuraspray-g3 measurement volume and reduced the average values. As a consequence the Accuraspray-g3 results should typically be somewhat lower than the average values based on the DPV-2000 measurements.

Using the Triplex II gun a larger measurement grid was applied. The side length corresponds approximately to the length of the Accuraspray-g3 measurement volume. Therefore, the differences between the DPV-2000 and the Accuraspray-g3 results decrease to −10%/+1% for the mean velocities and −2%/−4% for the mean temperatures. Differences of this magnitude appear satisfying. Due to the fundamentally different systematic approaches of both the diagnostic systems it is not possible to find a better accordance between DPV-2000 and Accuraspray-g3. As explained above the local particle data on the DPV-2000 measurement grid were averaged in the same way as it is implied by the Accuraspray-g3 approach. By selecting the appropriate DPV-2000 grid points which are covered also by the Accuraspray-g3 measurement volume it is achieved that the evaluation areas are congruent.

The standard deviation of the DPV-2000 measured particle velocities and temperatures are larger for the F4 gun than for the Triplex II due to the more stable operation without distinct arc fluctuations of the latter. As explained above corresponding data on standard deviations cannot be provided by the Accuraspray-g3 system.

The horizontal and vertical *intensity profiles* based on DPV-2000 and Accuraspray-g3 measurements show good qualitative agreements although different definitions of the plume intensity are applied. Using the DPV-2000 the intensity refers to the number of particles per time unit in the measurement volume. The Accuraspray-g3 detects optical intensities which are presumably influenced by the particle size and temperature.

Intensity measurement along the vertical and horizontal axis is less time-consuming with the Accuraspray-g3 than with the DPV-2000 and can be applied for the optimization of spray patterns e.g., if different powders are injected simultaneously via distinct nozzles.

4. Characterizing Spray Conditions of a Triplex II Gun

4.1 Experimental

DPV-2000 measurements of particle characteristics were carried out on a Multicoat facility (Sulzer Metco AG, Wohlen, Switzerland) during atmospheric plasma spraying with a multi cathode Triplex II gun mounted on a six-axis robot. The powder was 8% Yttria partially stabilized Zirconia Praxair ZRO-196. The process parameters are listed in Table 3.

Table 3 Spraying parameters for measurements of particle characteristics (slpm = standard litres per minute)

Current	500 A
Plasma gas	50 slpm Ar, 4 slpm He
Carrier gas	2,1 slpm Ar
Powder feed rate	15 g/min.[a]
Injector	Top[a]
Stand-off distance	150 mm[a]

[a]Unless stated as varied

The DPV-2000 measurements were operated on an 11×11 point grid in a plane normal to the gun axis in stand-off distance. The grid was dimensioned 30×30 mm^2. Measurement time on each grid point was 5 s, which allows for sufficient statistical support of the mean and standard deviations by some hundred single particle data at least in the central grid area. The spatial position of the central origin of the measurement grid ($x = 0$ mm, $y = 0$ mm) was maintained for all the following measurements.

4.2 Results and Discussion

Figure 9 shows the results of the measurements for a variation of the spraying distance. Apparently the plasma jet widens with increasing distance from the gun and thus enables the particles to distribute on a larger volume. Concurrently the plasma gas slows and cools down so that the particles are also decelerated and cooled.

It is conspicuous that the maxima of the particle flows on one hand and of the particle velocities and temperature on the other hand are located distantly. The fastest and hottest particles are found above and horizontally shifted referred to the position of the maximum flow rate.

At one cathode guns the powder is injected vertically in center of the gun and the plasma jet is rotationally symmetric. Particle velocity and temperature depend amongst others on the particle diameter and mass as well as on the injection velocity, which is controlled by the carrier gas flow. Smaller particles are accelerated and heated up to higher velocities and temperatures by the plasma gas than larger ones. Due to their smaller inertia they are also located rather above the maximum particle flux than below. As the plasma jet and the particle flux are symmetric to the vertical center line, only vertical offsets of the particle flow and the maxima of velocity and temperature can occur. This could clearly be observed using the F4 gun in the framework of the comparison measurements described above.

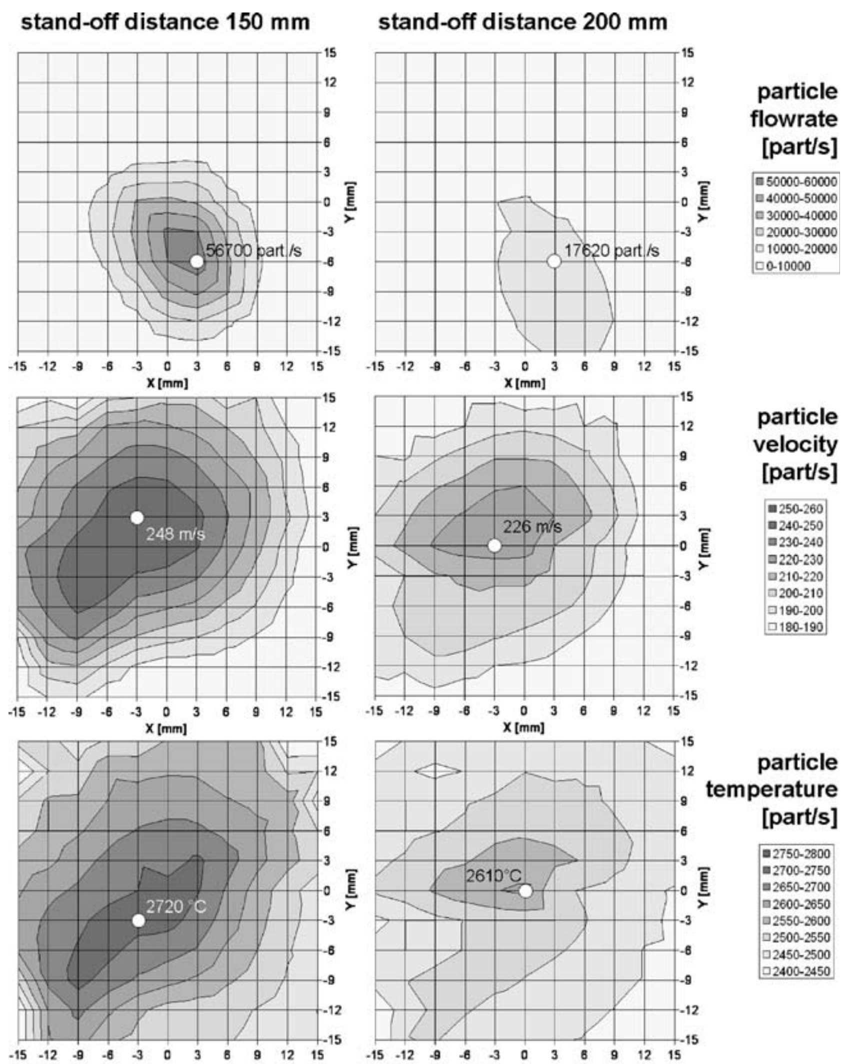

Fig. 9 Distribution of particle characteristics on a plane perpendicular to the gun axis at different stand-off distances (maximum values are specified)

In contrast, the plasma jet intensity of the Triplex II gun with three eccentric cathodes shows a clear triple symmetry. Its azimuthal orientation depends significantly on the plasma torch operation parameters, especially the current (Ref 11). The plasma gas is introduced into the gun through nozzles which are tilted relating to the gun axis. Thus a rotational momentum is transferred to the gas flow and hence the plasma generating arcs are twisted and stabilized (Ref 12). It must be expected that there is still an angular movement when the plasma gas expands and leaves the gun nozzle so that the formation of the plasma jet is three-dimensionally shaped. Consequently this has an effect on the momentum and heat transferred to the particles which are injected into this spatial intensity distribution of the plasma. The development of their trajectories will also show horizontal lateral components.

Figure 10 shows the effect of a variation of the powder feed rate starting from the same parameter set as stated above. For half of the powder feed rate consequentially the flow rate is also nearly the half. Here the kinetic and thermal energy of the plasma is distributed on a lower number of particles. Hence the maximum particle velocity and temperature increase as fewer particles are to be accelerated and heated.

Further effects of the Triplex II three cathode concept are shown in Fig. 11 when the three different injectors turned by 120° to each other are separately used. The maximum measured values differ slightly. This seems not to be significant regarding the limited spatial resolution of the measurement grid and the quite shallow distribution of the measured values in the surrounding of the maximums' positions. However, the distributions of particle flow rates, velocities, and temperatures are distinctly shifted against each other when operating each of the three-injector positions. In this regard the adjustment of the spray pattern can be effectively supported by diagnostic

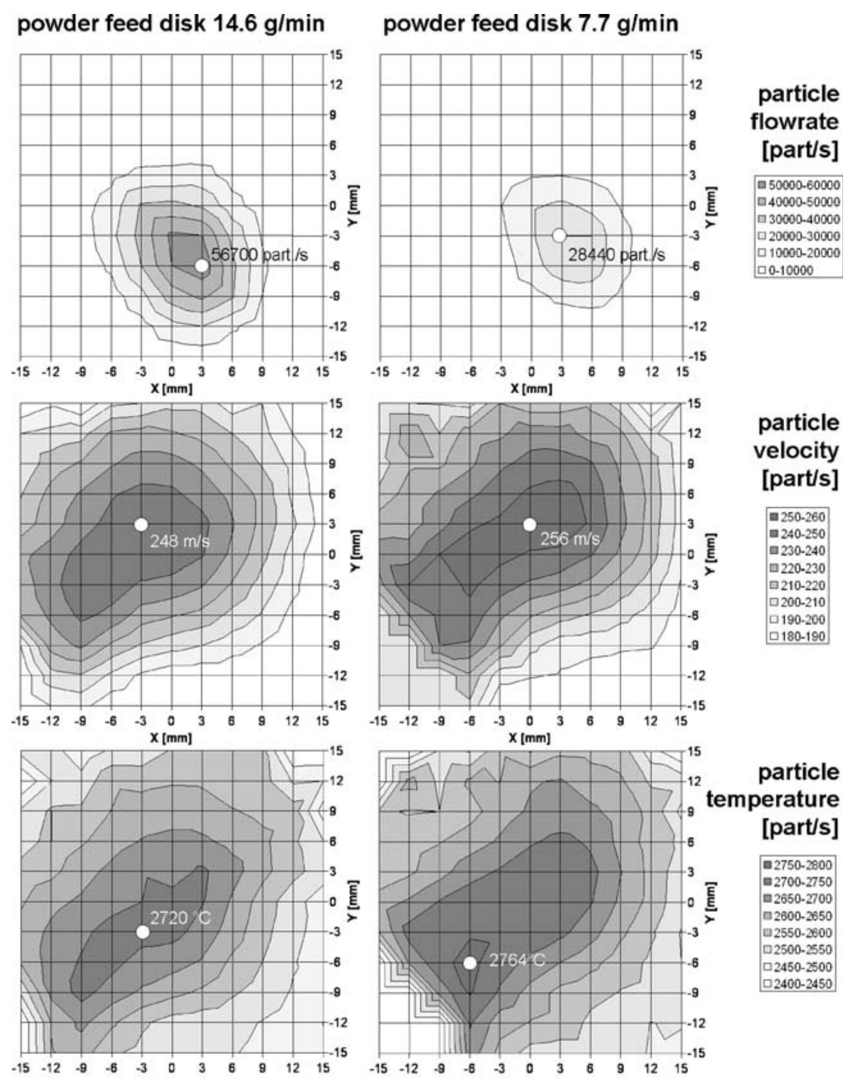

Fig. 10 Distribution of particle characteristics on a plane perpendicular to the gun axis at stand-off distance when spraying with different powder feed rates (maximum values are specified)

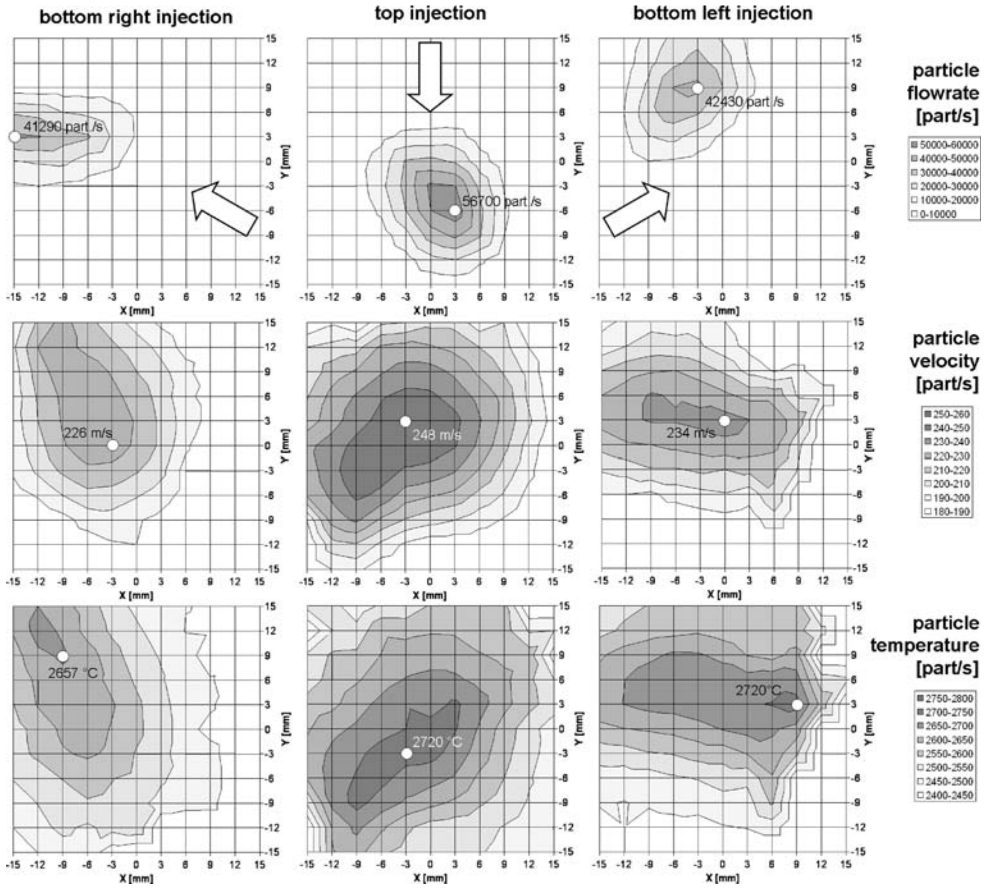

Fig. 11 Distribution of particle characteristics on a plane perpendicular to the gun axis at stand-off distance when operating each of the three Triplex II injectors (maximum values are specified)

measurements if multiple powder injectors are used. An example how to optimize spray patterns by a diagnostic system using simultaneously two different powders and injectors is given below, even though not the DPV-2000 but the Accuraspray-g3 was used in that case.

5. Optimizing of Spray Patterns

5.1 Experimental

When spraying anode layers of solid oxygen fuel cells (SOFC) (Ref 13) two different powders are introduced into the plasma plume of a Triplex II gun through two injectors which are turned to each other by 120°. In spray distance both the powder jets should form a joint spray pattern in order to achieve a homogenous composite and to avoid spraying the two powders in discrete layers.

The positions of the two spray pattern centers were determined with the Accuraspray-g3 diagnostic system. One component of this instrument is a CCD-camera. The analysis of its images provides intensity profiles along the radial cross-section of the particle plume at the distance to the gun where the sensor head is positioned. The position of the intensity maximum is used to describe the vertical coordinate of the spray pattern center. To achieve two-dimensional information the robot subsequently turns the gun by 90° around its axis and a second intensity profile is recorded. Now, the vertical axis on which this profile is evaluated corresponds to the inverted horizontal gun axis in spraying position. Thus the location of the spray pattern center can be determined in a plane perpendicular to the gun axis in stand-off distance. The application of the Accuraspray-g3 for that is very time-effective compared to a grid measurement carried out by the DPV-2000.

The most effective parameter to control the position of the spray pattern is the carrier gas flow. It immediately influences the particles trajectories. However, it can be varied only within certain limits. On one hand, a minimum is given by the demand of a stable powder flow. On the other hand, above a certain maximum the powder is injected too deeply into the plume and is crossing it to a large extend. Therefore, optimum carrier gas flows have to be found within feasible limits. Aside the particle velocities and temperatures have to be controlled in terms of boundary conditions when varying the carrier gas flow. This can also be done with the help of the Accuraspray-g3.

The measurements were carried out again with the Triplex II gun on the Multicoat facility mentioned above. The process parameters are listed in Table 4.

Table 4 Parameters for optimization of spray patterns (slpm = standard litres per minute)

Current	300 A
Plasma gas	25 slpm Ar
Carrier gas	2-4 slpm Ar (varied)
Stand-off distance	100 mm

One powder was an Yttria full-stabilized Zirconia (YSZ) with a mean diameter $d_{50} = 12$ μm. It was injected from the top (port A). The second powder was Nickel oxide (NiO), which was similar fine ($d_{50} = 12$ μm). It was injected from bottom right (port B) and bottom left (port C), respectively. The carrier gas flows were varied between 2 and 4 standard litres per minute Argon (slpm Ar). At lower gas flows no continuous powder flow was obtained anymore.

5.2 Results and Discussion

The results of the carrier gas variation introducing one powder YSZ or NiO in each case are shown in Fig. 12. The optimum combination is the injection of the YSZ powder by 2 slpm Ar from the top (port A) with the injection of the NiO powder by 3 slpm Ar from the bottom left (port C). Cross-sections of sprayed coating samples at these conditions did not show discrete layers of the two materials anymore as it was observed before at the non-optimized parameters. In this respect the given requirements could be met.

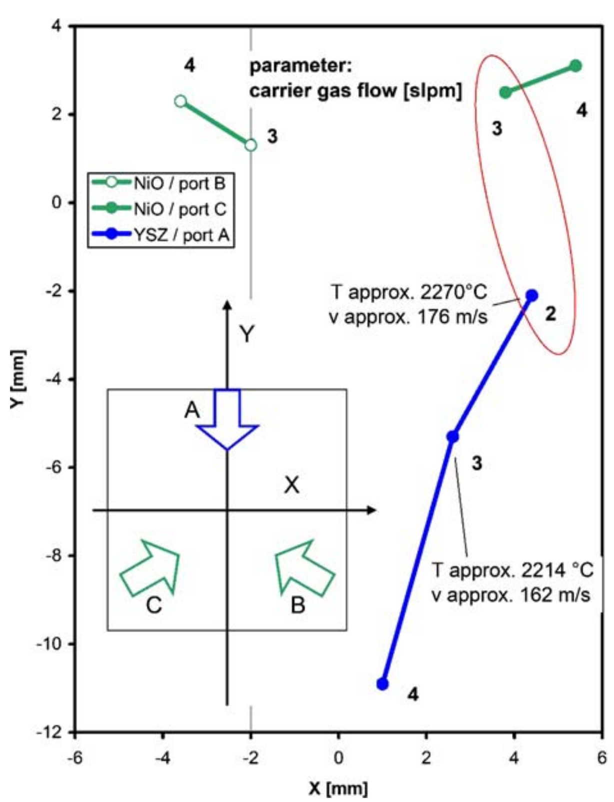

Fig. 12 Results of spray pattern optimization for YSZ and NiO powders

Table 5 Spray parameters for processing Lanthanumhafnate (slpm = standard litres per minute)

Current, power	520 A, 60 kW
Plasma gas	50 slpm Ar, 8 slpm He
Carrier gas	2,5 slpm Ar
Stand-off distance	100/125/150 mm (varied)

6. Application Limits

6.1 Experimental

There were also application limits identified for the DPV-2000 and the Accuraspray-g3 diagnostic system when using a few powder species in the framework of some other applications. A first example is a Lanthanumhafnate powder ($La_2Hf_2O_7$, fused and crushed, $d_{10} = 22$ μm, $d_{50} = 52$ μm, $d_{90} = 102$ μm). The spray parameters on the Multicoat facility with the Triplex II gun (above) are listed in Table 5.

6.2 Results and Discussion

Using the Accuraspray-g3 no particle velocity and temperature measurement was possible, in contrast the intensity profiles could be recorded properly by its CCD camera component. Starting with a spray distance of 150 mm the signal correlation between the two measurement channels was already quite poor. According to experience the correlation coefficient should ideally be better than 0.9 and stable, however, in this case it was widely varying about 0.7 resulting in unrealistic values for the particle velocity and temperature. Measuring in closer stand-off distances (125 and 100 mm) no correlation and hence no measurement values could be determined anymore. Similar problems with this powder material were also observed using a F4 gun at 50 kW power. Reliable measurements were feasible only at definite lower power levels below 30 kW.

The DPV-2000 was capable to determine the particle characteristics at spray distances of 150 and 125 mm. At 100 mm stand-off distance only the largest particles were detectable so that the determined means of velocities and temperatures are not representative for the whole particle entirety. The reason for the advantage of the DPV-2000 compared to the Accuraspray-g3 is the fact that the DPV-2000 is based on a single particle concept separating out all the particle signals which do not comply to a set of various assessment criteria. In contrast the Accuraspray-g3 uses an ensemble method. Here, the measurement values represent the mean characteristics of the particle collectivity being present in the much larger measurement volume.

For comparison an 8% Yttria partially stabilized Zirconia powder (Sulzer Metco 204NS, $d_{50} = 57$ μm) was sprayed at identical conditions. For this material the Accuraspray-g3 delivered feasible data without any problems. Figure 13 shows the results of the variation of the spray distance. The results appear reliable. Only at the shortest spray distance of 100 mm the correlation coefficient decreases below 0.9 resulting in a somewhat wider variation of the temperature evolution.

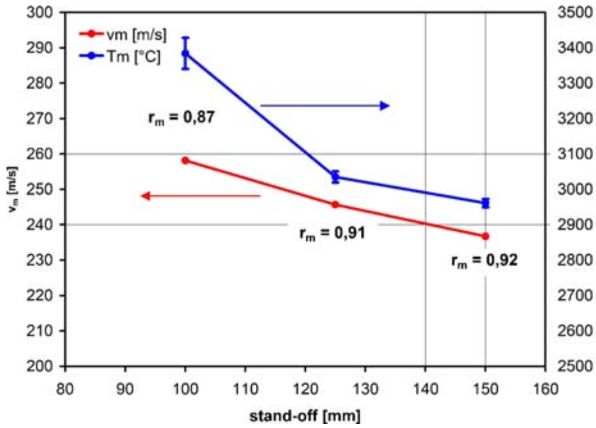

Fig. 13 Mean particle velocities and temperature of Yttria partially stabilized Zirconia powder at varied spray distance (the index *m* denotes that the values are mean values of the time-variant measurement data; the parameter r_m indicates the mean correlation coefficient; vertical bars identify the standard deviations of the temperature evolutions)

Another powder species which was experienced to be problematic in terms of measuring its particle characteristics is Mullite ($3Al_2O_3{\cdot}2SiO_2$, fused and crushed, $d_{10} = 17$ µm, $d_{50} = 30$ µm, $d_{90} = 47$ µm). Using the Accuraspray-g3 the measurement data of particle characteristics were found to be increasingly unreliable when reducing the stand-off distance. Operating a F4 gun at 41 kW power a critical threshold for the correlation coefficient of 0.75 was found. Above this value measurement data appear realistic and the variation limits are acceptable. Below 0.75 the results begin to vary widely and reach implausible regions.

Obviously the particle radiation of some certain powder species cannot be detected reliably at higher power densities of the plasma. The reasons could not be clarified completely yet. It is reported that measurement of particle temperature close to the torch exit is generally more difficult to carry out by the Accuraspray-g3 than by the DPV-2000 system (Ref 10). One mentioned reason, therefore, is that the plasma radiation is proportionally dominant relating to the particle radiation because of the much larger measurement volume of the Accuraspray-g3. As it is approx. 25 mm long plasma areas with lower powder density may be covered so that the ratio of the detected particle to plasma radiation becomes more disadvantageous. Yet another reported problem is that evaporated powder material might affect the identification of the particle radiation.

Indeed the detection wavelengths of the optoelectronic sensor are chosen such as to exclude plasma gas spectral lines. At the wavelength bands applied with the DPV-2000 and Accuraspray only some spectral lines of Ar with small intensities are found, other Helium or Hydrogen lines are not of significant magnitude. But it is assumed that the collected continuous background radiation is still intense enough to impact accurate temperature determination. This background radiation is caused by the electron-ion collisions and is present over the full emission spectrum (Ref 14). It can be direct or scattered by the particles (Ref 15). The latter would explain why the problems at high plasma power levels and short stand-off distances are occurring only in conjunction with certain powder materials and morphologies.

An attempt to explore the role of plasma radiation was the use of a modified sensor head for the Accuraspray-g3. Normally the radiation recorded by the optoelectronic sensor is filtered at wavelengths of 778 and 995 nm, respectively, each with a bandwidth of ±25 nm. In the modified sensor the first filter wavelength was altered to 715 nm. Using the Lanthanumhafnate powder (above) it was investigated whether this change of the analyzed wavelength would give any improvements by excluding potential disturbing radiation in the range of 778 nm. However, the experienced problems remained the same. So there is still a need of further clarification.

7. Conclusion

Considering the differences between the DPV-2000 and Accuraspray-g3 diagnostic systems conditioned by their different operating principles, the comparisons of the results are found to be in good agreement. This confirms the measurement accuracy of both the systems.

The exemplary applications given subsequently show the benefits of in-flight particle diagnostics as an important tool for process development and monitoring. The effect of parameter variations can systematically be analyzed and spray patterns can be optimized without time and effort of producing and investigating many sprayed samples.

The experienced application limits of the applied diagnostic systems show that there is still a need for further clarification. But it should be clearly noted that the identified limits existed only when spraying some certain powder species at elevated power level so that the overall benefit of particle diagnostics and the employed systems in principle is not affected.

8. Summary

Particle in-flight diagnostics play an important role in assessment and optimization of plasma spraying process parameters. Comparing measurements were conducted to screen the accuracy of particle velocity and temperature as well as intensity profile measurements with both the DPV-2000 and the Accuraspray-g3 diagnostic systems. The results are found to be in good agreement.

Furthermore experimental examples are given to show the potential for optimization of plasma spray processes opened up by the application of the particle diagnostics DPV-2000 and Accuraspray-g3. The effects of parameter variations can be investigated systematically and possible non-optimal operating conditions may be identified. Further on the application of plasma sprayed anode layers for solid oxide fuel cells demonstrates how diagnostic systems

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can be used for process improvement. The example shows that a joint spray pattern can be achieved when diverse powders are simultaneously introduced by different injectors. Thus, a homogenous distribution of the coating materials is ensured.

Finally some application limits of the used diagnostic systems are identified. Even though the reasons for the experienced problems when spraying powder like Lanthanumhafnate and Mullite could not completely be clarified yet, the described examples give some advice for the practical application of the used diagnostic systems.

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