Development of process data capturing, analysis and controlling for thermal spray techniques - SprayTracker

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Abstract. Thermal spraying processes are becoming increasingly important in high-technology areas, such as automotive engineering and medical technology. The method offers the advantage of a local layer application with different materials and high deposition rates. Challenges in the application of thermal spraying result from the complex interaction of different influencing variables, which can be attributed to the properties of different materials, operating equipment supply, electrical parameters, flow mechanics, plasma physics and automation. In addition, spraying systems are subject to constant wear. Due to the process specification and the high demands on the produced coatings, innovative quality assurance tools are necessary. A central aspect, which has not yet been considered, is the data management in relation to the present measured variables, in particular the spraying system, the handling system, working safety devices and additional measuring sensors. Both the recording of all process-characterizing variables, their linking and evaluation as well as the use of the data for the active process control presuppose a novel, innovative control system (hardware and software) that was to be developed within the scope of the research project. In addition, new measurement methods and sensors are to be developed and qualified in order to improve the process reliability of thermal spraying.

1. Introduction

The basic idea of the SprayTracker® system is the provision of a manufacturer independent diagnostic, evaluation and control system, which increases process reliability during thermal spraying and opens up new possibilities for quality assurance. In order to work efficiently, an implementation of this system in the respective spraying system concept is necessary. For this purpose, a data communication of the SprayTracker System and the spraying system is realized via PROFIBUS (Process Field Bus). This communication module is switched between the PLC control and the control panel (stand-alone computer with touch screen) of the spraying system. As a result, all spray parameters and spraying data recorded by the spraying system can be read, recorded and archived as well as actively controlled by SprayTracker. Until now, the process is only monitored by optical methods or sound emissions but not controlled actively based on the recorded real-time data. The connection with the plant parameters must be established in order to ensure the active process control, and thus quality assurance [1, 2].

The synchronous measurement of data from various source of the entire coating process is very important. Different types of parameters can be distinguished:

- System parameters
- Process parameters
- Coating parameters
- Compliance with work safety regulations

The SprayTracker serves as the central detection unit. All sensors are connected to the central detection unit via different interfaces. A software module accepts the manufacturing facility parameters completely automatically, regardless of the type and number. Additionally it provides a time stamp after a prior synchronization with the spraying system.

In parallel, other sensors can also be connected to this software module (e.g. optical sensor and acoustic data acquisition). These two measuring systems operate discontinuously. The NIR (Near-Infra Red) sensor provides particle velocities and particle temperatures. These have the greatest significance in the spray distance. A particle dosimeter can be also connected wirelessly.

To supply the system with data, numerous sensors are required, which are wired or linked wirelessly with the SprayTracker. The following table shows the possible diagnostic procedures, which can be combined with the SprayTracker.

Table 1. Selection of typical diagnostic procedures for thermal spraying, which can be combined with the SprayTracker system [3].

	Measuring method	Measured values
Passive procedures	CCD camera	v_{Pa}, T_{Pa}, particle distribution
	IR detection / IR camera	T_{flame}, T_{part}, temperature distribution
	Pyrometry of individual particles (eg DPV 2000, NIR sensor)	v_{Pa}, T_{Pa}, particle number density, particle size
	Particle Flux Imaging (PFI)	Open jet geometry or fluctuations
	Emission spectroscopy	Gas temperatures above 9000 K, statements on particle evaporation
Active procedures	CCD camera + laser lighting (PIV-Particle Image Velocimetry)	v_{Pa}, particle distribution (density)
	Laser Doppler Anemometry (LDA)	v_{Pa}, particle concentration density or distribution
	Phase Doppler Anemometry (PDA)	v_{Pa}, particle concentration density or distribution, particle size
	Particle Shape-Imaging (PSI)	v_{Pa}, particle concentration density or distribution, particle size and shape

Most of the methods mentioned in Table 1 have in common, that a spatially resolved and therefore restricted measurement takes place. In this respect, the combination of location-resolved optical measurement methods with integrating measurement methods, such as acoustic analysis for example, is recommended, which maps the overall process using further specific parameters. These acoustic analyzes are suitable for quality monitoring of spraying processes. The frequency spectrum allows a statement about the spray parameters as well as the detection of burst signals, which can indicate crack propagation in the layer [1].

The individual diagnostic methods have already been adequately researched [1, 2, 4-6]. The target was the combination of the methods and the mapping of the measured values on a common time beam. This allows a real-time analysis of the on-line diagnostics.

2. Experimental

Set-up of the SprayTracker system
To be able to use the SprayTracker as a stand-alone device, the concept illustrated in Figure 1 was expanded and necessary system components were procured. A passively cooled computer system serves as a central controller. Solid-state and conventional 2.5 "hard disks" were integrated into the electromagnetic compatible (EMC) housing. An additional dust and acoustic protection has been designed.
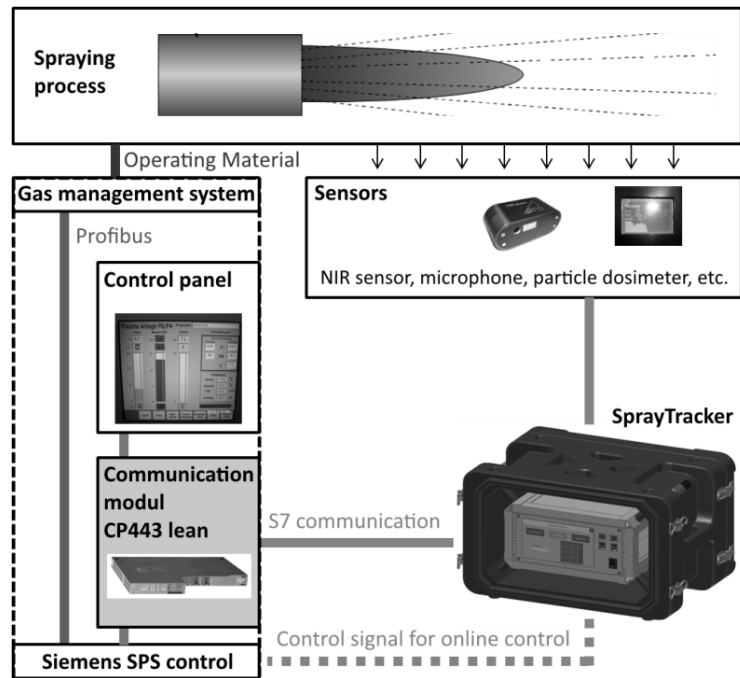

Figure 1. Scheme for the integration of SprayTracker into the spraying systems.

A touch screen is used for data control and manually input. The entire controller is fitted with a shock-resistant, screen-damped, air- and moisture-tight polymer-metal composite housing (Figure 2), whereby an additionally external monitor can be connected. Signal LEDs (light-emitting diode) indicate the operating state of the system. Figure 3 shows the user interface displayed on an external monitor while the system parameters are visible in the background.

Figure 2. Housing with computer and uninterruptible power supply.

Figure 3. User interface of the SprayTracker next to the plant control.

There are three operating modes: user (pure data visualization), spraying specialist (with additional functions, such as limit setting for process control) and system administrator (manufacturer support, for example, for system expansion). No further user surfaces are accessible to the user in order to avoid unauthorized system malfunctions. There is another operating level for the expert and the supervisor.

Storage concept and data management system
For storing an SQL (Structured Query Language) database is used, which is located on an SQL server. This server is installed in the housing and can record data completely independently of the coating system. The software module communicates with all sensors and the process control. All data records have time information, which is synchronized with the process control. Different data sets (including different data formats) can be sorted and managed chronologically.The saving concept is designed to fulfil the following functions:

1. Complete data record during the coating process and archiving of data.
2. Alarm triggering in case of failure.
3. Visualization of current data as well as archive data.

In order to obtain useful information for process control or for the observation of the degree of the electrodes wear, the acoustic data must be matched with other system parameters. In addition, noise must be actively gated out by matching with background measurements. The SprayTracker system meets these requirements by using special quasi-digital and digital filter techniques (bandpass and notch filters).

3. Results

Numerous spray tests were carried out to illustrate the need of process monitoring and active process control. In plasma spraying tests, new and worn electrodes were used to compare measurement data of different wear conditions of the spraying system. Figure 4 shows the different wear conditions of the electrodes and their arrangement in the system. On the right hand side, the positioning of the spray gun in front of the sample clamping is observable.

Figure 4. New and worn electrodes, electrode setup in the plasma spray gun and spray gun setup.

By comparing the surface of the resulting cotings in Figure 5, hardly any differences in coating quality are visable, whereas different production conditions (new and worn electrodes) were used. This fact often leads to problems in quality assurance, because inferior coatings are interpreted as supposedly good coatings.
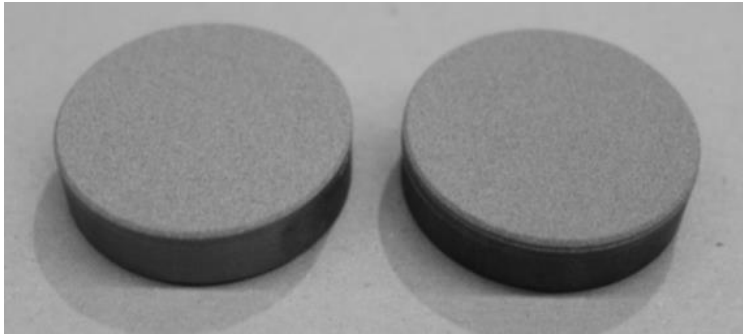
Figure 5. Steel samples with Al_2O_3 / TiO_2 coating, produced using new (left) and worn electrode (right) of a plasma spraying system.

Upon closer investigations on the micro structure of the coatings the effect of the new and worn electrodes on the layer quality is clearly visible, Figures 6 and 7. The coating deposition and the homogeneity of the layers decrease with increasing wear of the electrodes due to reduced deposition efficiency. This results in a reduced coating quality, appearing by clusters of pores, increased roughness and a significantly decreased hardness.
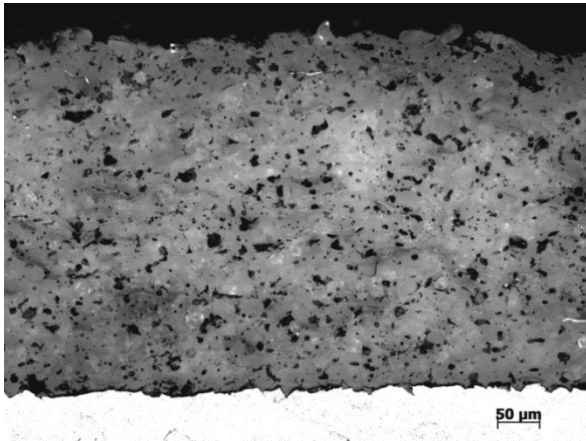

Figure 6. Al_2O_3 / TiO_2 layer sprayed with new electrodes with parameter set H8 Ar34 l/min (Optimized industrial parameter).
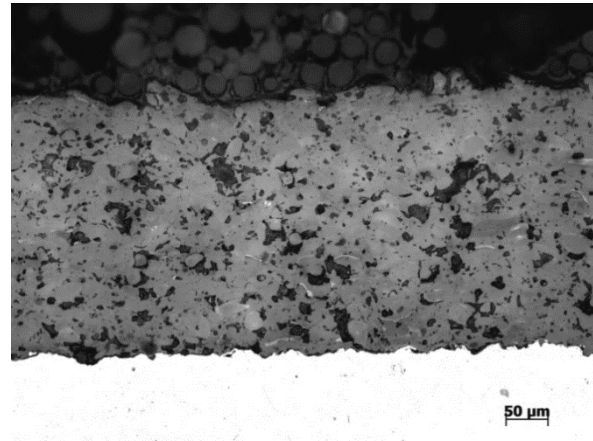
Figure 7. Al_2O_3 / TiO_2 layer sprayed with old electrodes with parameter set H8 Ar34 l/min.

Further tests show that small changes in the gas flow rate cause significant changes in the coating properties. With the reduction of the hydrogen flow rate, the layers become generally thinner, with the reduction of the argon flow rate, the layers become slightly thicker. This can be explained by the lower kinetic energy of the plasma jet, which is associated to an increasing particle presence time in the spray jet. This leads to a higher particle temperature and thus to an increased deposition rate. However, the layers become either more porous or the self-tension in the layer increases, which also promotes the formation of microcracks. To prove the fact, that the layer quality variations correlate with the process parameter fluctuations and the diagnostically ascertainable characteristic values, results of the NIR sensor and acoustic measurements during hydrogen flow rate variation are presented in Figure 8 and 9.
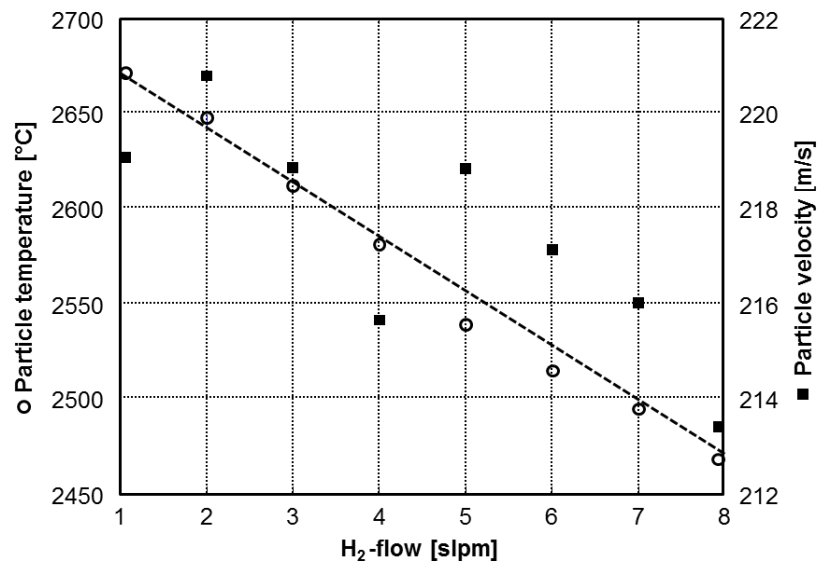
Figure 8. Particle temperture and particle velocity vs. hydrogen flow rate.

The variation of manufacturing facility parameters led to distinct differences in spray jet temperature, particle velocity and coating application (Figure 8). Both parameters were measured by the NIR sensor. This proved that the online process monitoring is basically suitable as a quality assurance tool. The user is thereby abled to recognize a changing coating quality in an early stage of the production process.
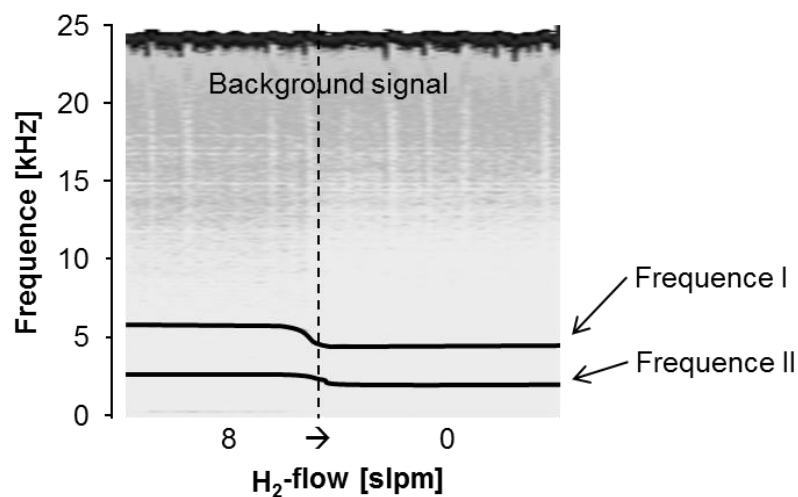

Figure 9. Shift of main frequency caused hydrogen flow rate reduction from 8 l/m to 0 l/min.

The process fluctuations were also visible in the acoustic spectrum. The characteristic main frequencies of the process and their shift to lower values with decreasing hydrogen flow rate are observable in Figure 9. Thus, the observation of these frequencies is suitable for monitoring the process gas flow.

4. Summary

The SprayTracker system, developed within the framework of a research project in cooperation with IfU, CBS and Westsächsische Hochschule Zwickau, is a completely new and innovative system that meets the need for new holistic process analysis and control systems by carrying out numerous measurement and control tasks simultaneously.

- Data recording of the real-time process parameters of the spraying system as well as comparison of the input variables to defined set points.
- Recording the position data and the kinetic parameters of the handling system (including the robot position and movement, the position and feed of the component manipulators, the linear feedforward and the rotational speed of the shaft rotary table).
- Workpiece monitoring (e.g. component temperature, deformation, layer thickness).
- Analysis of inflight particle parameters (particle velocity, temperature and particle distribution) as well as the spray jet profile (shape, divergence and angular deviation).
- Connection possibilities for user-specific sensors, particle dosimeters, gas detectors, etc..
- Visualization of monitored characteristics in customizable user profiles.
- Different operating modes or user rights to avoid incorrect operation.
- Complex database system with intelligent data filtering, redundant data storage and data transmission.
- User interface as an aid for the plant operator with limit visualization and alarm functions.
- Possibility of an autonomous plant control concept (initially with operating instructions, also as a closed-loop system in perspective).

Due to the above-mentioned application possibilities, the system is a sensible extension for existing plants as well as an attractive option for new plants. Through the SprayTracker system, spraying system manufacturers are able to offer their customers an innovative quality assurance tool that fulfills all diagnostic basic functions and can be customized.

Acknowledgments

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