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On The Way to Shot Peening 4.0

Advanced process and quality management for digitisation in automated pressure peening systems

SHOT PEENING is a special process with free-flying spherical particles as tools. The work of the balls on the surface can therefore not be controlled as easily as in a machine tool. Accordingly, the digitisation of process and quality parameters for the requirements of Industry 4.0 is difficult to achieve.

Generations of engineers have been working for more than 150 years to gain control of the flying shot peening balls and their effect on the surface. The goals of shot peening are, in particular, safe and reproducible processes in order to achieve reliable cold work effects and the introduction of residual compressive stresses that significantly increase the service life of components under dynamic loads. For the future, the simulation of shot peening processes is a promising approach to reduce development time, optimise processes, and save energy.

In order to clarify the fundamental development steps of blasting and peening technology against the background of the three phases of industrialisation up to the present day, it is first worth taking a brief look at historical records.

Industry 1.0 - Water and steam power
The first industrial revolution from around 1800 onwards was characterised by the introduction of water and steam power as energy sources for processes and drives. It was not until 1870 that Benjamin Tilghman showed with his first sandblasting blower how steam could be used in an injector nozzle for blasting medium to mechanically process surfaces. However, these blasting applications could by no means be represented in a stable manner in terms of process technology.

Industry 2.0 - Electrification
In the second industrial revolution, the advancing electrification around 1900 allowed for the first time the realisation of decentralised drives that were used to generate compressed air in compressors. This enabled the development of much more powerful blasting systems, which made stable processes possible in the first place. Subsequently, it was also possible to develop closed pressure blasting systems which are still very similar to today's design. Nevertheless, continuous monitoring of the processes was hardly possible.

Industry 3.0 - Electronics and control technology
With the third industrial revolution around 1970, electronics and control technology also found their way into shot peening technology. The sensory recording of data in programmable logic controllers (PLC) allowed the targeted control and also the regulation of manipulated variables in the shot peening process. For example, the introduction of the MagnaValve for electromagnetic flowrate control of peening media was a milestone in this development. With computer technology and increasingly smaller and more powerful processors, the control possibilities were further improved. However, work is still being done today on a conclusive technical concept for the complete recording of the actual process and quality parameters.

Systematic process and quality management for Industry 4.0
With the fourth industrial revolution now underway, far-reaching challenges are coming up with the complete digitalisation of process and quality management in shot peening machines. This results in a multitude of tasks to be solved such as the development of extended sensor technologies on the one hand and the digitalised mapping of the relationships between machine parameters, process parameters, and quality parameters on the other.

From machine parameters to process parameters
The kinetic energy and amount of media accelerated by the compressed air in the nozzle determines the impact characteristics of the media in the process (see figure 1). Since these process parameters cannot be set directly, they must be controlled via the machine settings. Thus, only the control of the machine parameters will provide a stable shot peening process.

The **nozzle-to-part configuration** as spatial arrangement (distance and direction), as well as temporal allocation (movement) of the peening nozzle to the workpiece, essentially influences the impact angle as one process parameter—it also indirectly influences the impact speed. For complex workpieces, robots are therefore often used for path-guided movements of the nozzle (Figure 2).

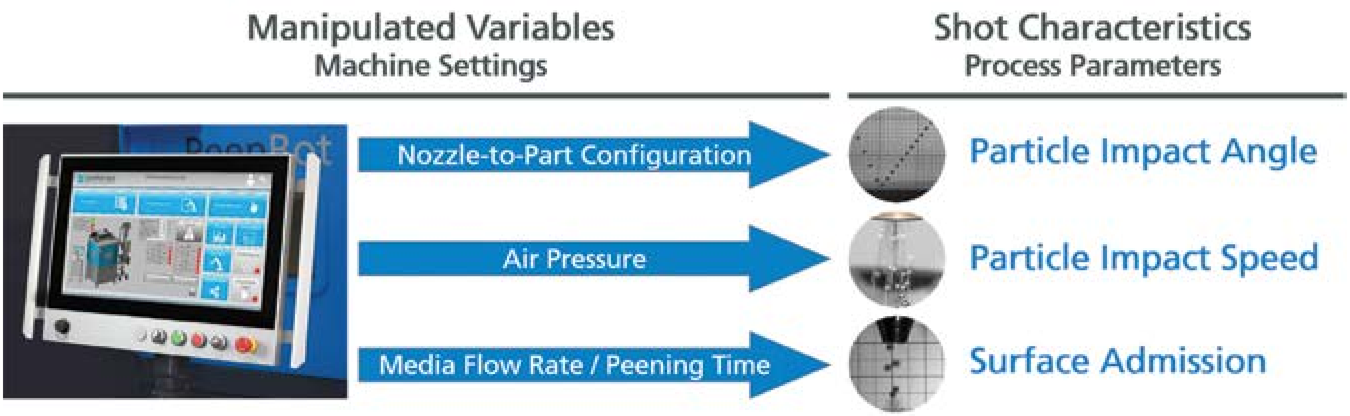

Figure 1: Machine parameters and their influence on the process parameters

The manipulated variable or the machine parameter **air pressure** influences the particle velocity and thus the process parameter impact velocity. The adjustment is carried out by means of pressure control, if necessary, for several independent peening nozzles. Monitoring of the air flow rate serves to detect possible leakage and wear conditions of the peening system, including the nozzle, which will have unintended influence on media acceleration.

The **media flow rate** through the peening nozzle determines the amount of particles per area on the surface, and must be controlled. Depending on the type of media, different actuators and sensors are used to adjust and measure the throughput. The MagnaValve combines an actuator and a flow sensor in one unit. As a rule, the peening time or cycles need to be set properly so that the surfaces to be processed are fully covered.

Figure 2: Spatial and temporal assignment of peening nozzle and workpiece

Direct monitoring of process parameters

The compliance and control of set machine parameters is the general state of the art in process technology and does not pose any fundamental technical difficulty in digitisation as all the control variables mentioned are physically measurable variables that can be mapped digitally.

But beyond that, how helpful would it be if the process variables could also be directly monitored and digitally mapped? With such a direct mapping, the digital twin of the process would no longer be just an image of the machine settings, but an image of the shot peening process itself. The technologies required for this are already available even if they are still being fine-tuned for serial use.

The main process parameters to be mentioned here are the **media properties** grain material, grain hardness, grain size and grain shape. While the first two can only be meaningfully checked before the blast machine is filled, measuring systems with cameras and software that dynamically check the size and shape of grains in free fall have been available for years. Such systems become even more interesting if they constantly monitor the medium circulating in the peening machine. The first solutions for permanent grain size monitoring of free falling media in the flow path are already on the market (Figure 3).

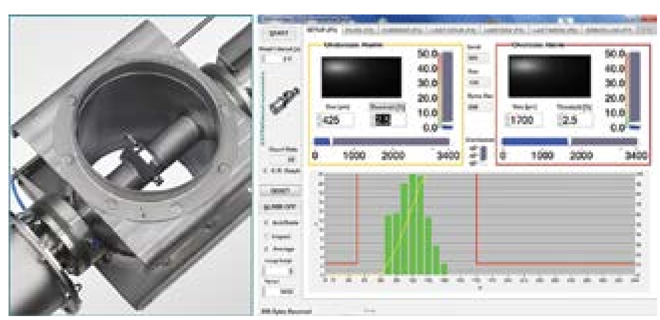

Figure 3: Dynamic analysis of the grain size of circulating abrasive (DYNA Instruments)

The **impact angle** of the peening particles can be monitored with a high degree of process reliability by permanently logging the movement paths of a robot for peening nozzle guidance and the movement of the workpiece digitally via the robot's axis drives.

Several systems based on the evaluation of laser signals are already on the market for the direct determination of the **impact velocity** or the grain velocity at a certain nozzle distance. An unprotected installation in peening systems is only possible to a limited extent. sentenso offers a completely different approach with the evaluation of live video images

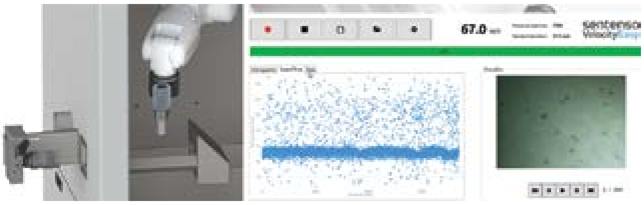

Figure 4: Process-related media velocity measurement with high-speed camera and VelocityEasy (sentenso)

from a high-speed camera. With the help of the evaluation software named VelocityEasy, the media movement is made visible and evaluated in detail (Figure 4). With the associated vector:on Media Speed Management, a peening system can adjust and calibrate itself completely independently to the desired value via the correlation between peening pressure and particle speed.

The **media flow** rate control at the machine works with adjusted and calibrated sensors or control systems. The problem here is the dynamic change of the media properties due to use or refilling, which in turn can significantly influence the sensor values and thus falsify these values. In addition to the peening time, which is easy to monitor, it is required to continuously recalibrate the flow control system to ensure that the surface is properly impacted. sentenso offers a fully integrated and automated measurement and control system for this purpose—the flux:on Media Flow Management. It is based on a cyclone fixed in the peening chamber and a weighing container located outside. By automated insertion of the peening nozzle into the cyclone, this system measures the real media flow rate through the nozzle. The measurement can be recorded and evaluated at any time and as often as required for calibration. The system is also able to readjust itself as the deviation between target and actual values increases (Figure 5).

Figure 5: Process-oriented throughput monitoring with flux:on Media Flow Management (sentenso)

Furthermore it needs to be stressed that regular and conscientious maintenance of the peening machine plays another important role for process stability which can be supported by tools such as predictive maintenance supported by the machine control system.

Determination of quality parameters at the workpiece

The quality or surface parameters to be set with the shot peening process at the workpiece—such as peening intensity, degree of coverage, and residual stress—are also very special and require different measuring techniques ranging from simple subjective-visual assessment using a magnifying glass to complex residual stress analysis using X-ray diffractometers. Digitalised measuring systems are increasingly entering the market in this area as well. The aim is to achieve the most automated, objective, and quantifiable recording of the radiation effect on the surface.

Simulation of shot peening processes

In the future, shot peening processes can be simulated in advance of process development on the basis of continuous digitisation from machine to process and quality parameters. Accordingly, the effects on the component surface can be predicted more reliably on the basis of material-specific and empirically obtained digital data when varying process parameters. For example, expected shot peening intensities and degrees of coverage on the surface can be displayed in false colours (Figure 6). Artificial intelligence (AI) can make further contributions by determining the data model via an AI algorithm from measurement series. The AI model can be subsequently refined with the help of additionally generated data. The model can be simplified if media and material surface conditions are being kept constant during one series of data acquisition.

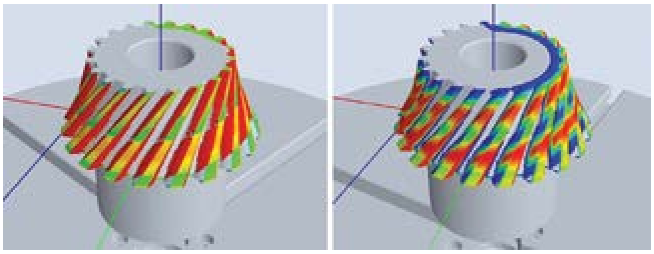

Figure 6: Simulation of quality parameters like shot peening intensity and coverage

An approach that goes beyond this is the solution of the inverse problem of peening process technology. It is desirable that, again with the help of artificial intelligence algorithms, we were able to set a desired target condition of the peened surface directly via automatically determined process parameters and with machine parameters derived from these (Figure 7).

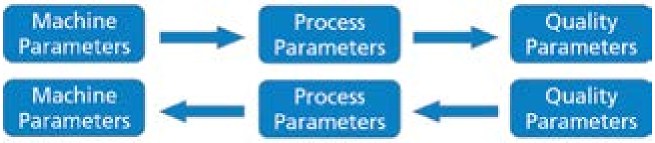

Figure 7: Reversal of simulation through AI-based determination of machine parameters from quality parameters