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How Visualization Saves Money in R&D

Introducing SHOTVISUAL Software for Shot Visualization and Surface Treatment Optimization

MECHANICAL PRE-STRESSING TREATMENTS using shot peening are widely used in automobile, aeronautic and biomedical industries to improve mechanical parts and structures. These cold-working processes use spherical media called shot, and introduce surface compressive residual stresses that are found to enhance the fatigue resistance of intermediate- and high-strength metals and alloys. They protect the structure from fracture as fatigue cracks propagates mostly from surfaces during operation. The gain in strength and fatigue life observed after such a treatment can be spectacular while offering the advantage of being relatively easy to perform technically.

It is, therefore, not surprising that major companies working in very different areas have now turned their attention to such process/applications and to the control of the operating conditions in order to optimize coverage or to achieve targeted surface properties.

Nevertheless, in order to make additional progress and bring the technology to the next level, there is need to understand how shot behaves inside the peening chamber, and how the operating parameters (shot density, velocity, chamber geometry) will affect the shot impact on pieces and parts. Although the measurements of steel sphere velocities and angles can be relatively straightforward, not much is known on the way these behave collectively. The situation becomes even worse for the case of ultrasonic shot peening in which the spheres are propelled by an ultrasonic vibrating wall (a sonotrode), and bounce around in a blind peening chamber.

It is, therefore, widely believed that a direct visualization of the shot from hard sphere simulations could provide an interesting added value to the problem posed, while also saving R&D money used for cumbersome measurements of sphere bouncing, chaining methods relating the operating conditions to materials properties, validity assessments, post-treatment analysis, etc. In fact, because most of these aspects can be hardly reconciled, most of the design of peening chambers and the choice of process parameters remain empirical to a large extent, making it costly, time consuming and partially optimized, especially when complex industrial parts are to be considered.

In this respect, a promising solution is provided by the software SHOTVISUAL which is capable of stimulating a large number of shot peening possibilities for complex parts in industrial conditions while keeping the computation time to a minimum.

An event-driven molecular algorithm is used to model the behavior of an assembly of spheres, inspired by the statistical physics treatment of vibrated granular gases. A finite number of hard spheres (the shot) is driven by a velocity stream or by a vibrating boundary sonotrode (for the case of ultrasonic shot peening) and contained within defined boundaries. Such event-driven simulations allow studying all sorts of industrial conditions, including for parts that have complex geometries, defined by a finite element mesh (FEM), made of triangular elements.

One, thus, has the possibility to conduct efficient 3D simulations in short computing times, achieving in certain situations a 1:1 ratio between effective peening time and the simulation time. The realistic operating process parameters such as shot diameter and density, velocity stream of the blaster, amplitude and frequency of the ultrasonic sonotrode, as well as the process duration are read and act as input data for the event driven simulation.

The use of an OpenGL C++ library permits a direct 3D visualization (optional) that renders the individual trajectories of the spheres and meshes during the simulation. Using the software, one can now eventually correct process parameters by visualizing how the shot impacts the parts. Once the operating conditions are roughly optimized, impact related data are saved for each FEM meshed triangle: coordinates, impact time and velocity, impact angle. Such data can afterwards be used for a second refinement of the operating conditions, and provide now quantitative relationships between the process control parameters and the various impact properties, including surface coverage which is constrained by international standards (SAE J2277). Let us now consider two examples of the SHOTVISUAL software in the following.

Figure 1 on page 38 shows a typical impact distribution of an aluminium sample obtained from SHOTVISUAL in a cylindrical peening chamber geometry. The software permits

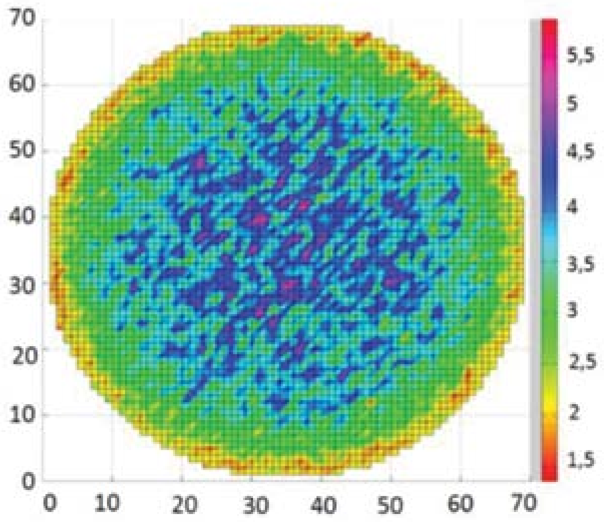

Figure 1: Impact velocity field (in m/s) for an ultrasonic shot (20 kHz) peened aluminium sample. Chamber diameter 70 mm, height 45 mm, Shot diameter 3 mm. Shot quantity 20 g.

the detection of the effect of the operating conditions on the surface coverage and the impact velocities. Here, one realizes that the coverage is not homogeneous and further analysis indicates that the heterogeneity is essentially driven by inelastic collisions with the side-walls that lead to partial adsorption characterized by weakly moving steel spheres close to the sample. An appropriate change in the operating conditions (for example, an increase of the amplitude) reveals that this flaw can be cured, whereas alternative solutions that may be seen as obvious, for example, an increase of the shot density, turn out to be counterproductive. In fact, a larger number of colliding spheres increases locally the shot density and produces an inelastic collapse of the colliding spheres, which results in an enhanced heterogeneity of the treatment.

The second example is provided in Figure 2 and will also serve us to provide a short survey of the software SHOTVISUAL. A first step consists in reading the CAD triangular mesh representing the part, e.g., an aluminum spur gear. All relevant surfaces in direct contact with the spheres are selected and grouped according to their nature (part, chamber, sonotrode) and their material characteristics that permit to define corresponding collision restitution coefficients. A library of velocity dependent restitution coefficients for various materials (Ti, Ni, Al,…) is used for this purpose.

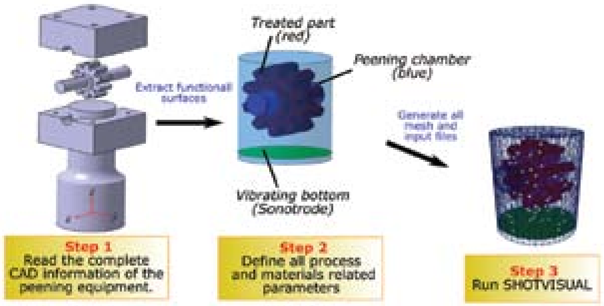

Figure 2: Schematics of the SHOTVISUAL simulation.

Once the various required mesh and input files are generated, the simulation can begin. The C++ library OPCODE then constructs an Aligned Axis Bounding Box (AABB) based collision tree for each of the colliding possibilities (shot, walls, sample, eventually sonotrode) and the program conducts fast sphere-mesh collision detection queries in order to rebuild the trajectories with time of each of the shot spheres.

The user can choose between two versions. A first one uses real-time visualization that is more demanding in computation time and is mainly to be used for exploratory phases. The second version without any visual feedback (console mode) can be used for the simulation of long treatment times.

Specifically, a simulation of five (5) seconds of treatment (500 spheres) for this case study, when ran in single CPU mode on a simple laptop PC (Intel® CoreTM i7 CPU, at 1.73 GHz), took 30 seconds and 7.5 minutes to complete in "Console_ mode" and in "visualization mode" respectively. Ultimately, the dynamics of the shot and the impact properties can be

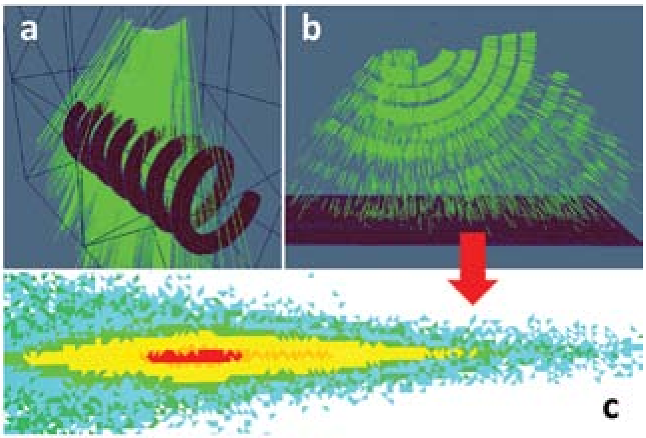

Figure 3: Air blasted shot peening on a steel spring (a) and on a moving plate from a rotating turbine (b). The latter leads to a characterization of the impact distribution (c), and it is found that the heterogeneous coverage results from the spread in output velocity and angle from the turbine.

Series of simulations permit to correct this flaw and to optimize the process by adapting both the plate velocity and the angular velocity of the shotblasting turbine.

visualized on various industrial parts—springs, gears, plates, etc.—that have been subjected to a surface treatment (Figure 3).

Taken together, these new and exciting developments clearly open the possibility to fully control the shot peening process, blasted or ultrasonic, while also offering the possibility to obtain easily targeted surface treatments without numerous labor hours. This furthermore reduces the need to spend time and money in routine experimentation and analysis. ●

References:

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For More Information

If you have question or a query about shot visualization and surface treatment optimization, the software SHOTVISUAL can help. Please visit www.shotvisual.com or send an email to Emmanuel Guyot (Emmanuel.guyot@utt.fr). The workgroup SHOTVISUAL also provides:

- **chamber design,**
- **impact analysis on dedicated work parts,**
- **optimization routes,**
- **and design-build services.**

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