COST 526 – Project *CH2*

Final Report

Numerical Calculation of the Process Parameters, which Optimise the Gas Turbine Blade Coating Process by Thermal Spraying, for given Spray Paths

Dr. Martin Balliel, Dept. TGNTT
Project Lead: Hanspeter Lang, Dept. TMURH
ALSTOM (Switzerland) Ltd
CH-5242 Birr H4/3, Switzerland

1. Introduction

The blading of a gas turbine, core of many combustion-fired power plants and virtually all jet engines, has to be protected from the hot gas stream, which drives the turbine. This can be achieved by different techniques, such as cooling air, metallic coating or thermal barrier coating (TBC), which provides a thermal insulation for a blade through its low thermal diffusivity. Thereby the metal temperature of a cooled blade can be kept lower, while increasing the hot gas temperature or decreasing the amount of cooling air, both lead to higher turbine power and efficiency.

The present project is concerned with the process of applying TBC on hot gas surfaces of a turbine blade. ALSTOM uses air plasma spraying (APS) of a Zirconia ceramic to form the TBC. Conventionally, the APS process for a particular blade is manually developed based on experience, which requires a time and resource consuming trial & error series of spray tests complemented by non-destructive and destructive evaluations of coating thickness and quality.

2. Goal of the project

The project targets the following points:

- The development of criteria and strategies for the optimisation of the coating process, which include the coating thickness, porosity distribution and the total coating time as parameters of the objective function.
- The development of methods for the optimisation of a spray path for complex 3D shapes by taking into account equipment, process and tooling limitations.

3. Simulator, calibration, quality function and optimisation algorithms, including assessment with respect to alternatives

Offline simulation tool

An offline simulation tool for the coating process models the complete set-up consisting of a robot, a plasma spray gun and a blade. All degrees of freedom and limitations (maximum speed, collision etc.) of the robot and the blade are considered. The user can define paths of the spray gun and analyse the resulting coating

thickness and porosity on the blade surface. The latter is computed using a predictive software developed at ALSTOM.
The simulation tool takes into account the spray distance, spray angle, spray time, characteristics of the gun and ceramic powder, and the complex component geometry. Figure 1 depicts screen shots of the simulation tool showing the robot, gun and blade set-up (left) and a turbine blade with a colour mapping of the coating thickness (right).

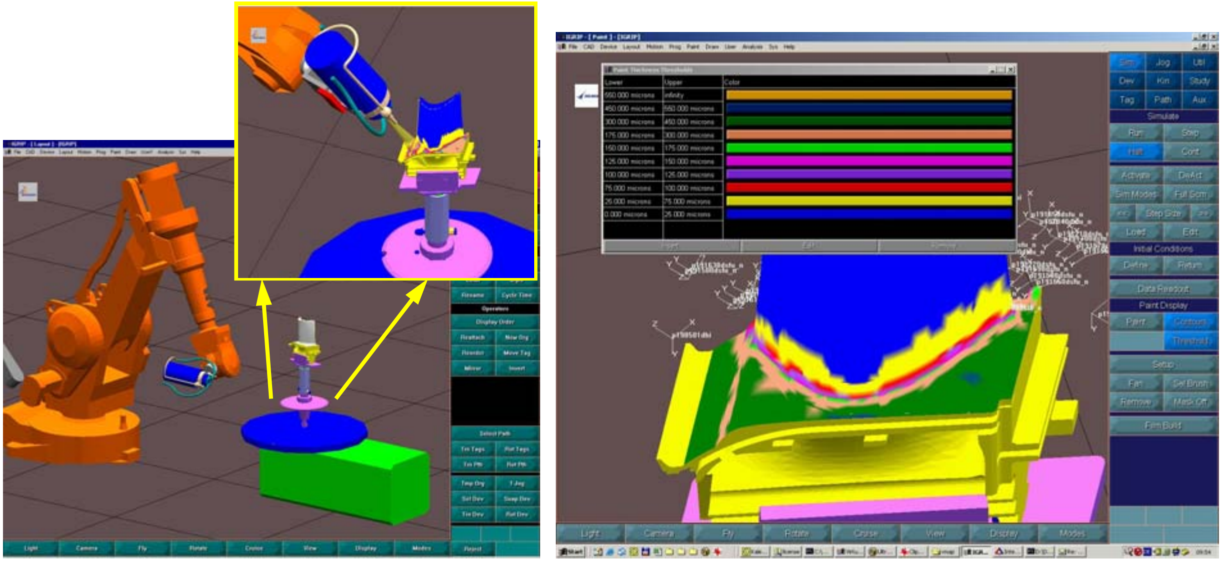

Fig. 1: Simulation tool showing robot, spray gun, blade on holder (left) and a partially sprayed turbine blade. Colours of the hot gas surface indicate local TBC thickness (right).

During project execution it became apparent that an additional baselining of the simulator was needed. The target is to achieve a prediction of coating thickness, which is both, qualitatively right and quantitatively within acceptable limits to enable an offline assessment of coating quality. In turn this allows a viable offline spray process optimisation, which offers clear advantages vs. conventional trial & error.

Therefore racks of sample plates have been sprayed with variations of selected spray parameters in stationary and dynamic tests. The resulting coating thickness was measured by 3D scanning in a 13x10 or 15x12 matrix. Then the measured coating thickness data was interpolated by cubic splines using MatLab software to yield analytic functions for easier subsequent fitting of simulation parameters.

In an optimisation loop a set of 6 numerical parameters was varied to minimise the discrepancy between measured spray result and simulator prediction, resulting in an improved set of simulation tool parameters, see Fig. 2.

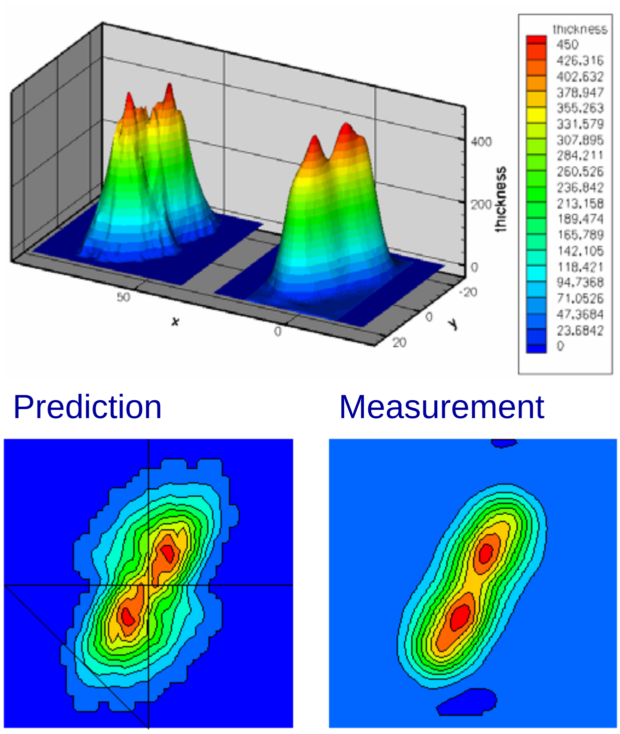

Fig. 2: Predicted (left) vs. measured (right) spray pattern after optimisation of 6 simulation tool parameters. The accuracy of the coating thickness simulator is substantially improved compared to the initial parameter setting.

Objective function

An objective function has been defined, comprising specifically the predicted coating quality, i.e. TBC thickness and porosity, and total process time as called for in the project targets. The objective function is not finalised yet and needs to be reviewed.

Optimisation environment

As optimisation software for the project the Java Optimisation Environment (JOE) developed by ALSTOM (Switzerland) Ltd is applied. The programming language is Java. This makes the optimiser especially suited for the application on different computer platforms.

The program implements several modern optimisation algorithms, such as evolutionary strategies. The program was successfully applied in different areas inside and outside ALSTOM, namely for optimising Francis turbines, gas turbine burners, compressor blades, or wind turbine airfoils.

One of the main strengths of the available optimisation software is that it can handle noisy objectives. These can occur when the optimiser is coupled with predictive software such as the coating offline simulation tool. Specific algorithms (response surface techniques) allow finding good solutions with a relatively small amount of evaluations. This is especially useful in the present case where a complete prediction with the offline simulation tool may require a few minutes.

For both, the additional task of baselining the simulator and the offline spray path generation the same optimisation software Java Optimisation Environment (JOE) was applied.

4. Main scientific outcome

The performance of ALSTOM's coating process simulator has been extensively investigated by spray experiments. Based on the hardware results a set of 6 parameters was varied in a numerical optimisation loop, yielding an improved set of simulation tool parameters, see Fig. 2.

- Coating strategy

This step aims at defining the most appropriate coating strategy. Considering the high number of variables in a spray path definition for a blade/vane, a reduction of variables is needed for both, easier manual input and for numerical optimisation.
To achieve this the idea was projected to partition the surface to be coated into subdomains, which can be treated individually. Such subdomains are worked on in sequence with the spray result of all previous subdomains as starting condition for the next subdomain. This ensures that so-called 'overspray', e.g. spraying of surfaces adjacent to a primarily targeted surface, is taken into account at subdomain boundaries, see Fig. 3 (left).

- Parametrisation

This step requires a parametrisation of a spray path for each subdomain as defined in the coating strategy. This means that the possible spray paths have to be described in a mathematical form with a limited number of free parameters. Fig. 3 (right) shows as an example the spray path parametrisation of a concave side airfoil with 7 parameters.

Both, coating strategy and parametrisation are not finalised and need to be reviewed once more offline programming experience is accumulated.

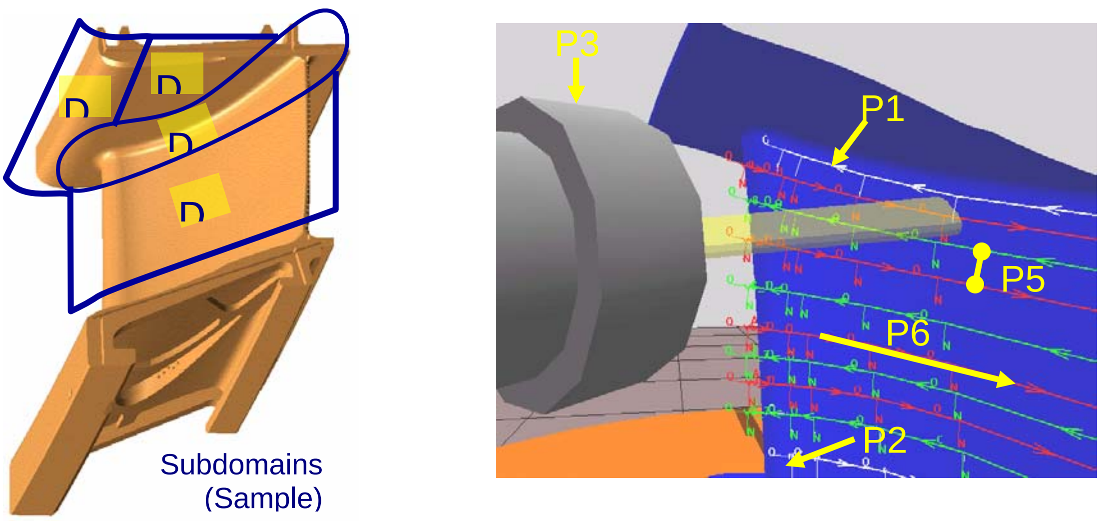

Fig. 3: Division of coated surface into subdomains to ease optimisation (left) and sample of a parametrisation for the concave airfoil side (right).

5. Main technical outcome

The offline simulation tool for the coating process is used for manual spray path generation. The complete set-up consisting of robot, a plasma spray gun and a blade is taken into account. Fig. 1 shows a sample process for manual spray path generation including coating thickness prediction.

In parallel, the usability of the offline simulation tool was reworked to simplify the definition of a spray path for a given gas turbine blade/vane. Approaches comprise a library of geometrical elements, e.g. robot, gun, table, fixtures, and writing of so-called 'macros' to automate repeating tasks. In particular, this reduces the number of input variables, enabling an improved manual operation as well as a more efficient numerical optimisation.

6. Collaboration within COST 526

Participated in COST526 Workgroup meetings and COST526 Swiss group meeting (Prof. Hofmann, FH Aargau in Windisch, Switzerland) with progress presentations and technical discussions.

7. Cooperation with industry

The project leader ALSTOM (Switzerland) Ltd is a leading manufacturer of gas turbine and combined cycle power plants.

8. References

ALSTOM Power: http://www.power.alstom.com/

ALSTOM Power – Gas Turbines for Simple and Combined Cycle:

http://www.power.alstom.com/home/equipment___systems/turbines/gas_turbines