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CVI-CaP: Virtual certification platform of the pantograph-catenary interaction

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Abstract

The approval process of new rolling stock is essentially based on inline testing campaign. Beyond the cost of these tests, the slowness of the approval process penalizes the development of the railway industry.

This paper presents the virtual certification for the catenary-pantograph interaction. This project, called CVI-CaP, is a partnership between CIMES and SNCF Réseau. The main objective of this project is to develop a platform which reduces the number of inline tests and hence the time to market for new rolling stock.

The virtual certification project is divided into several stages:
1. Dynamic simulations of the pantograph-catenary interaction including variability analysis,
2. Feasibility of the virtual certification platform including process automation, data management and artificial intelligence,
3. Evaluation of aerodynamic effects of the pantograph for the current collection quality with CFD simulations,
4. Evaluation of high frequency behaviour of the pantograph with multi-body simulations,
5. Modelling current collection and electric arcs with electromagnetic simulations.

The virtual certification involves inline testing campaign, tests on laboratory bench-testing and multi-physics simulations. Multi-physics simulations help to reduce the gap between test and simulation. Machine learning technology is applied to convert the amount of data into valuable knowledge (detection of critical configurations, correlation between test and simulation, variability analysis).

Keywords: virtual certification, multi-physics simulation, variability, data management.

1 Introduction

The certification of a new rolling stock is subject to an approval based on an inline testing campaign on the railway infrastructure. One of the main purpose of the approval phase is to validate the compliance of the rolling stock regarding current collection quality according to the European standard (EN 50367). The compliance shall be evaluated in all operating situations and in all climatic conditions.

These tests, carried out by the rolling stock manufacturer, are imposed by the railway infrastructure manager and controlled by the railway safety authorities. Then, the three-part relation resulting from the collaboration of the rolling stock manufacturer, the pantograph supplier and the rail network manager allows to plane the mandatory tests on operated railway tracks.

Beyond the cost of these tests, the time to market of rail solutions is heavily penalized by:
- the amount of the approval procedure,
- the lack of availability on operated railway tracks.

During the past few years, in addition to the will to accelerate approval process, considerable advances in numerical simulations were made leading SNCF Réseau and CIMES's teams to develop a project for a virtual certification for the pantograph-catenary interaction. The acknowledgement of numerical simulation as an alternative certification tool with respect to the existing standards (EN 50318) does not mean the removal of all in line tests but the reduction in their number.

The acceleration of the approval process will be obtained by adopting a new methodology. In addition to tests on operated railway tracks, it will include:
- laboratory bench-testing of the relevant subsystems,
- multi-physical and multidisciplinary numerical simulations,
- machine learning technology to use all tests and numerical simulation data.

The goal of the project is to study the feasibility of a virtual certification platform which answers the current challenges and allows:
- the integration of numerical simulation softwares (existing or forthcoming),
- the integration of bench-test and in line measurement data,
- the variability analysis on the key parameters.

2 Methods

Data from both numerical simulations and physical tests will interact in the virtual certification platform. Numerical simulations allow a stochastic approach with variability analysis whereas physical testing is reduced to a deterministic approach.

The SNCF Réseau – CIMES partnership has started by integrating OSCAR software developed by SNCF Réseau into the virtual certification platform. OSCAR allows the simulation of the dynamic pantograph-catenary interaction. REGIO 2N project has been selected as a proof of concept to approve the methodological approach.

When the REGIO 2N train was put into service, 500 configurations had been identified for the simulations with OSCAR and then for the tests on operated railway tracks. The methodology adopted in the virtual certification consists in simulating all the operating situations (more than 3000 configurations for REGIO 2N).

The use of the modeFRONTIER software, developed by ESTECO, as support for the virtual certification offers many advantages:
- automation of the evaluation of all operating conditions;
- development of customised design of experiments.

OSCAR is compliant to the EN 50318 regulation for the simulation of the catenary-pantograph dynamic interaction. This standard requires an accuracy of 20% compared to the tests, which is not enough to guarantee an acceptable level of prediction. To improve the accuracy of the simulation, it is necessary to take into account the following physical phenomena: aerodynamic effects and high frequency behaviour of pantographs.

The aerodynamic effects become more and more important as train speed increases. To study these effects, STAR-CCM+ software, developed by SIEMENS, was used. The study is decomposed into two parts:
- the validation of simulations which follow standardized railway cases;
- the characterization of the aerodynamic efforts at the pantograph.

The high frequency behaviour of pantographs should also be studied. Indeed, OSCAR calculates a fast Fourier transform of the raw signal. All signals above 20Hz are cut, then an inverse transform is performed. The SIMPACK multibody simulation software, developed by DASSAULT SYSTEMES, is used to evaluate the influence of the high frequency behaviour of pantographs and the railway vehicle dynamic.

Finally, the simulation of current collection and electric arcs with STAR CCM+ will be a specific study. Numerical electromagnetism tools allow two types of simulations:
- the current conduction into the structure;
- the shorting (creation of the arc) between the pantograph and the catenary, for example during a contact loss.

3 Results

The OSCAR simulation has been totally automated through a MATLAB script in order to modify the main parameters of the simulation easily:
- type of catenary (1.5kV or 25kV),
- type of rolling stock (1 to 3 electric multiple units),
- train speed (up to 160km/h),
- temperature range (-10°C to +50°C).

Post-processing has also been automated to verify the quality criteria for each operating situation:
- current collection quality: ratio between the standard deviation and the average value of the contact force [Figure 1],
- duration of contact loss,
- maximum catenary uplift [Figure 2].

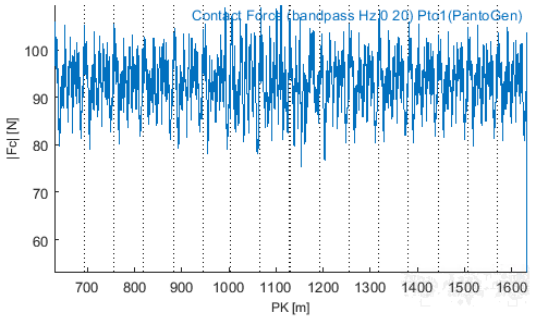

Figure 1: Contact force between pantograph and catenary

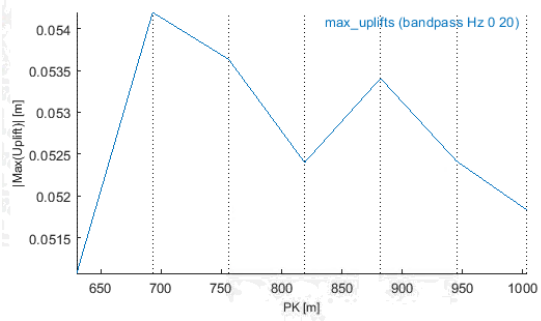

Figure 2: Maximum uplift of the catenary section

The OSCAR simulations has allowed to verify that:
- the catenary 1.5kV problematic is linked to the current collection quality for high temperatures due to the expansion of the cables,
- the catenary 25kV problematic is linked to the maximum uplift because of its architecture with the stitch wire. Extensive work has been done to take into account the aerodynamic effects with more precision in the OSCAR simulations.

Different situations were simulated:
1. Tunnel entrance at 40m/s
The static pressure inside the tunnel corresponds to the values of the standard [Figure 3].

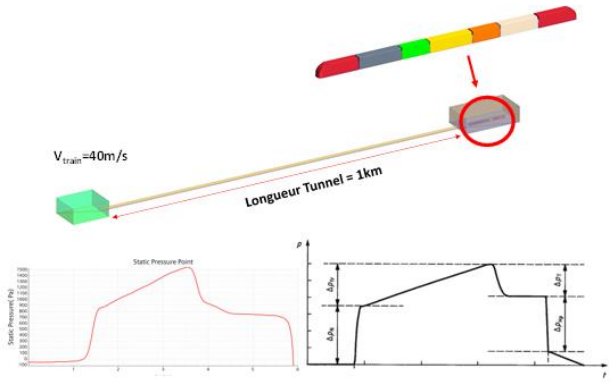

Figure 3: Static pressure field (simulation vs EN 14067-5)

2. Crossing between two trains travelling at 40m/s
The pressure fields on the train walls allow evaluation of the forces applied on the rolling stock [Figure 4].

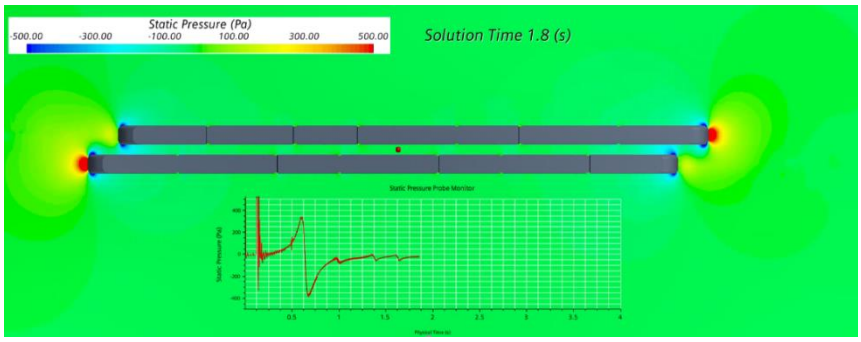

Figure 4: Pressure static analysis during a train crossing

3. Cross-winds influence
The efforts due to the combined effect of the moving train, the intensity and the direction of the wind can be characterized [Figure 5].

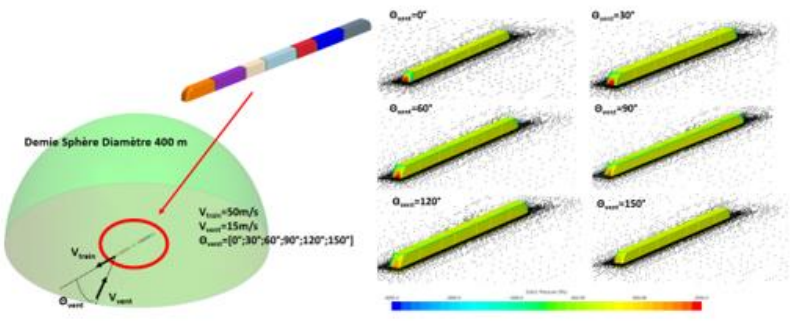

Figure 5: Calculation field for crosswinds analysis and results

Influence studies have been carried out to calculate the lift coefficient Cz of the pantograph:
- train direction (pantograph oriented in front knee or rear knee),
- number of units (between 1 and 3 pantographs).

CFD simulations allow to determine the aerodynamic efforts on the different parts of the pantograph. These efforts are implemented in a pantograph plane model to deduce the force between the pantograph and the catenary [Figure 6].

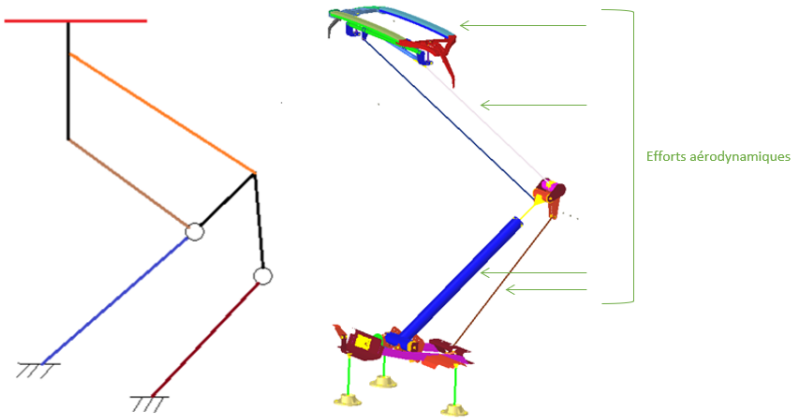

Figure 6: Pantograph kinematic simplified at plane problem

The virtual certification platform uses the modeFRONTIER interface [Figure 7]. Firstly, the OSCAR integration demonstrates the efficiency of the solution for data processing [Figure 8], identification of critical cases and variability analysis.

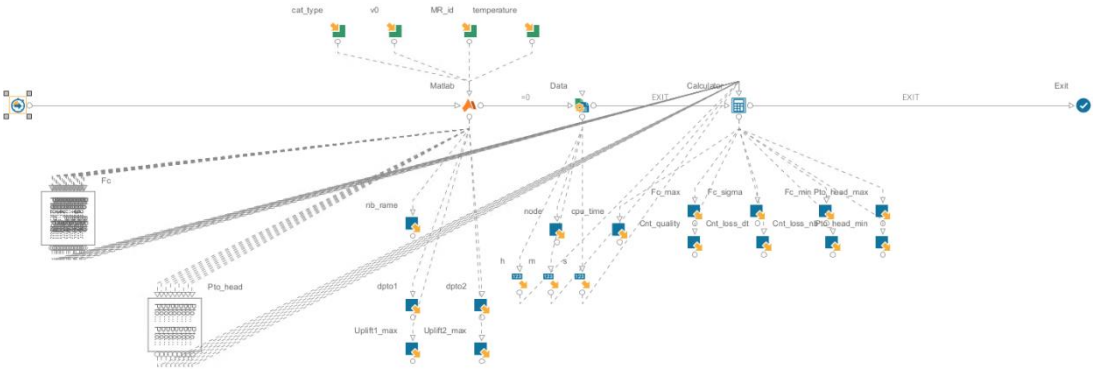

Figure 7: Workflow modeFRONTIER
(management of input-output and computational automation)

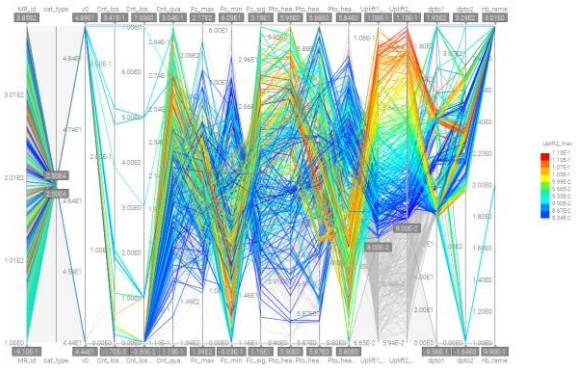

Figure 8: Example of modeFRONTIER chart for data analysis

4 Conclusions and Contributions

The integration of OSCAR in the virtual certification platform has considerably reduced the number of studied operating situations through the identification of critical cases. It will accelerate the approval process through a complete automation of analysis and the use of an HPC cluster. Moreover, this methodology allows to perform variability analysis on the several key parameters. CIMES has doubled the computing capacities of its HPC cluster in order to reduce CPU time so that the platform is in line with the industrial constraints.

Improvement ways have been studied to increase prediction of OSCAR simulations, especially on the aerodynamic aspect. Operating situations such as entrance into a tunnel, crossing trains or the crosswinds effect have been examined. In addition, the influence of train direction and number of units on the lift coefficient of the pantograph has been also studied.

The creation of the virtual certification platform has been made in the modeFRONTIER environment. Full automation of model set up, calculation launch and post-processing has been demonstrated with OSCAR. In the end, the objective is to add the various technological bricks mentioned, such as the contribution of CFD simulations.

The modelling of the high frequency pantograph behaviour is feasible with the SIMPACK software. However, the lack of data on the pantograph has not yet allowed the development of a complete multi-body model dedicated to the pantograph.

At the same time, the CVI-CAP project includes the construction of a research and development laboratory for current collection within Technopôle Transalley with a test bench for static current collection in a catenary infrastructure configuration, a dynamic current collection bench and a hybrid bench. These test benches will allow to characterize the behaviour of the pantographs in their entirety. The results from these specific tests can also be used to improve the test-calculation correlation, and generate a database for the virtual certification.

The simulation of current collection and electric arcs include complex physical phenomena. Its integration into the virtual certification platform require a skill development in teams.

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