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CAE simulations are essential for refining and correcting the design of mechanical systems: an example of a steam turbine casing

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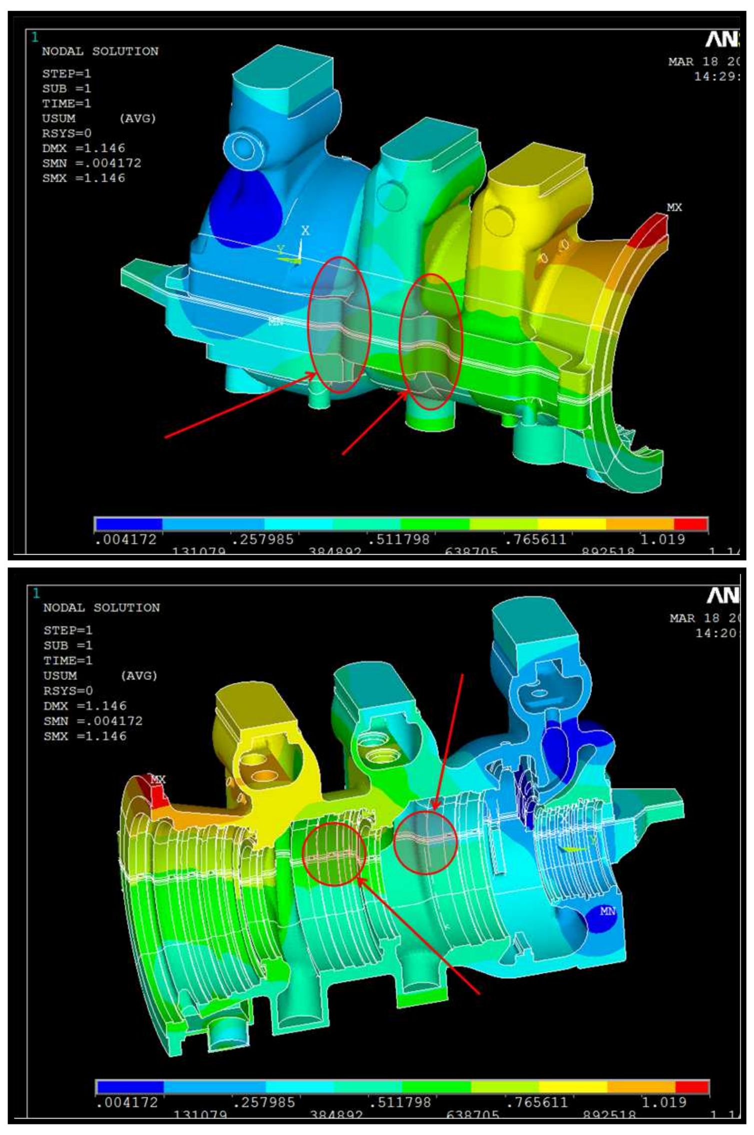
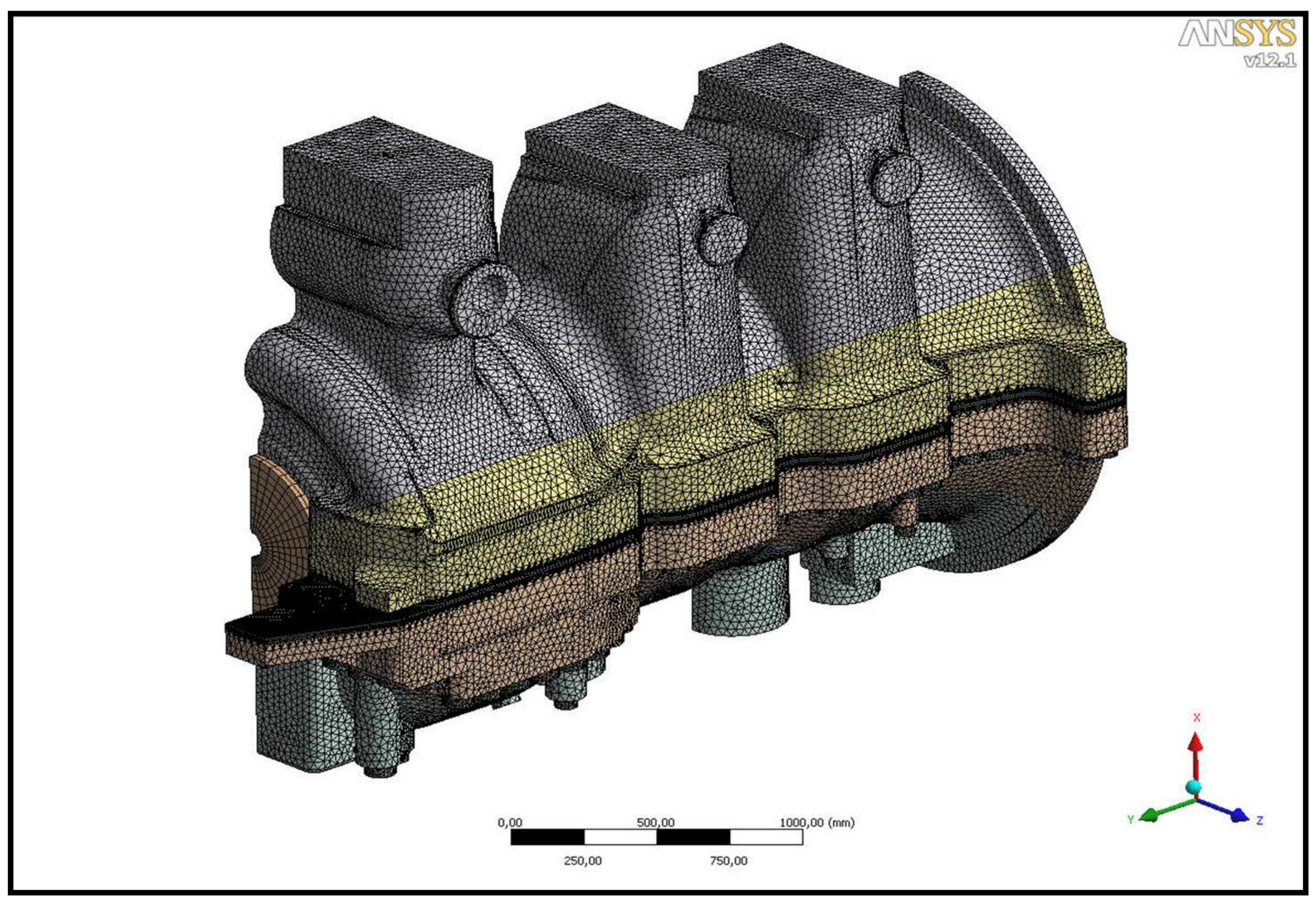
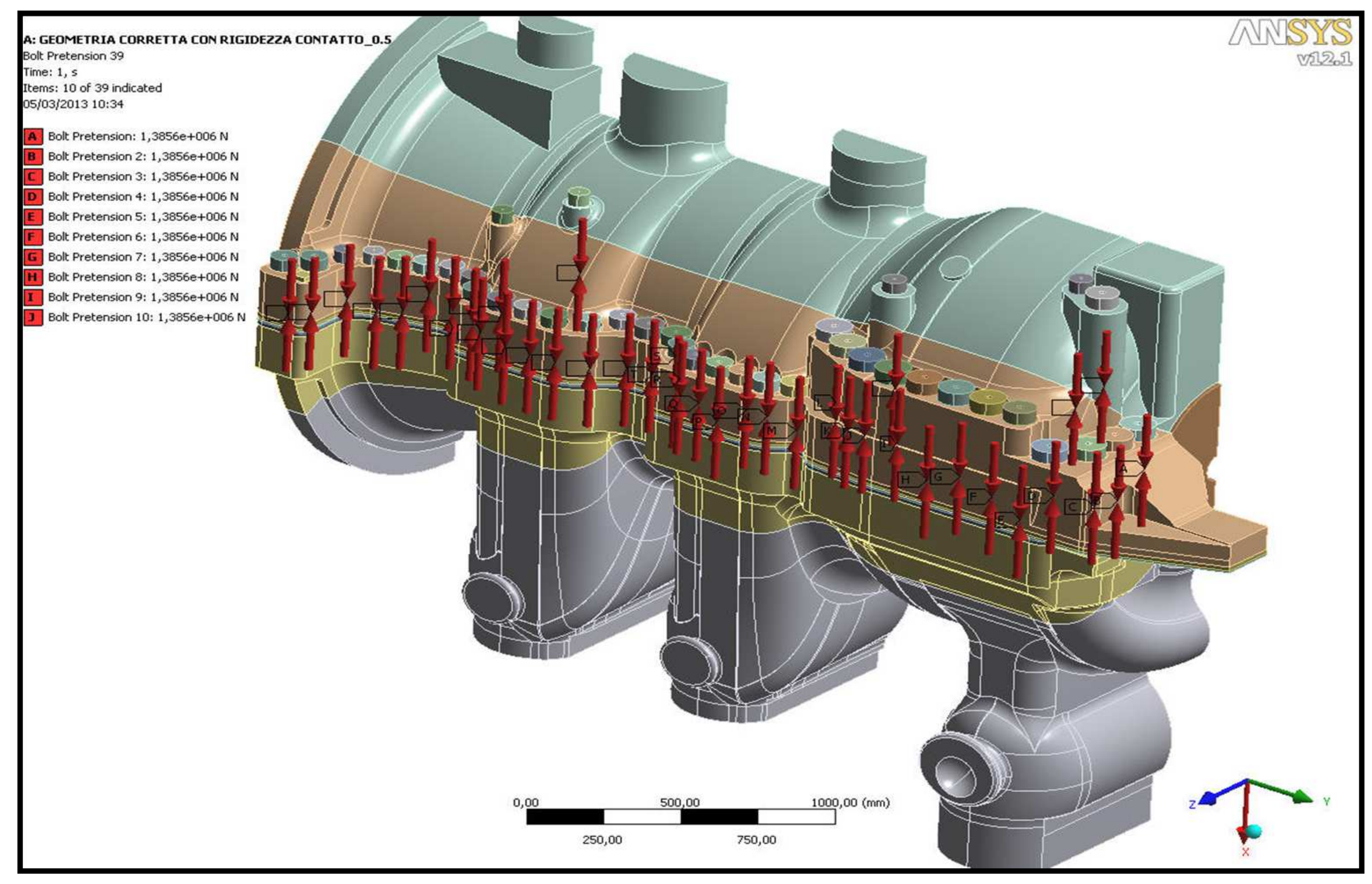
The case of a steam turbine casing that had leakage problems during the hydraulic test is presented. The simulation with the 3D model of the casing that allowed to identify the cause is described, Numerical results are compared to and validated by experimental results obtained by means of pressure sensitive films. The efficiency of the proposed modification in the design has been tested by means of numerical simulation and proved by the final positive hydraulic test result.



Model of the half casing showing points at the flange where leakage occurred during hydraulic test.

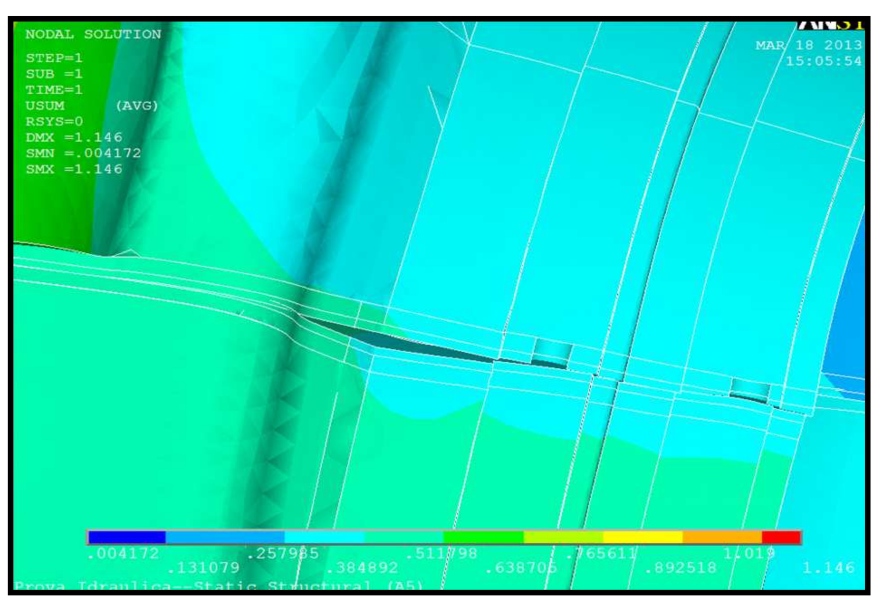


FEM model of the half casing. Symmetry about vertical plane and non-linear friction contact are used.

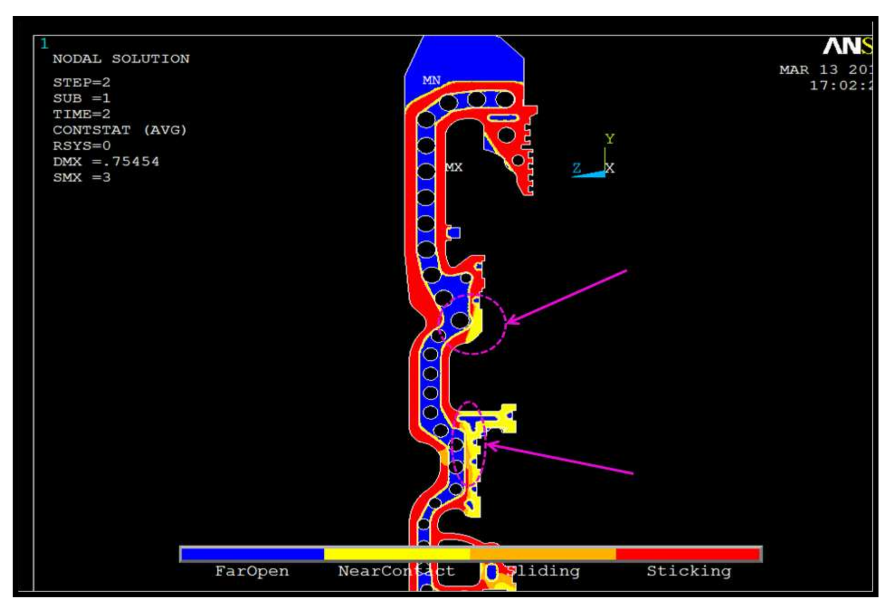


Preloads of the connecting bolts have been applied, as well as the internal water pressures, corresponding to the test pressure in the 3 different internal sections.

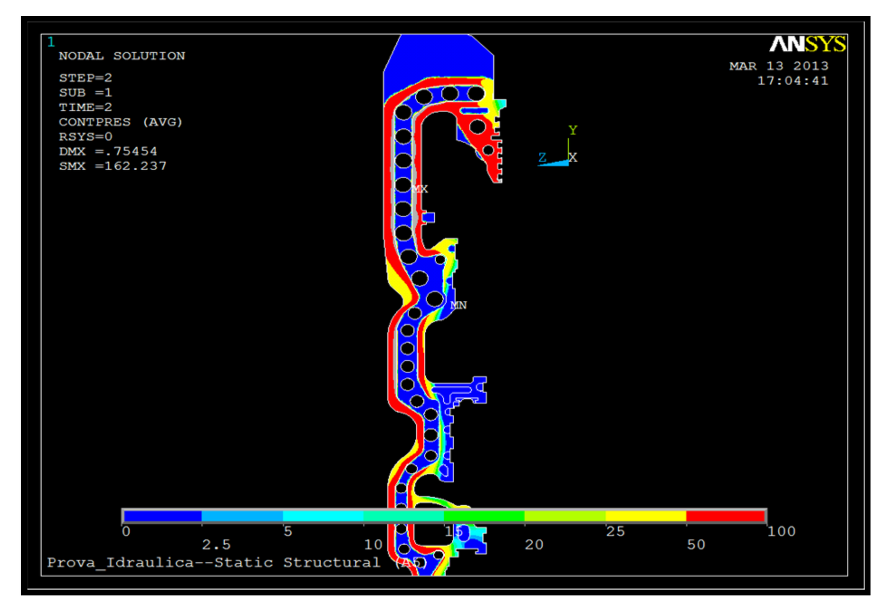
During the hydraulic test at 1.5 of nominal pressure some leakage occurred in two points of the connecting flange. In order to investigate the cause of the leakage and propose some modification in the design, a rather refined model of the casing was prepared. Non-linear contact must be used in all the contact surfaces, bolt preloads have been applied as external forces, and internal water pressures have been applied. Results of the non linear calculations confirmed the loss of contact in two restricted zones where the leakage occurred.



Gap between flange surfaces in one of the two critical points caused by the applied forces simulating the hydraulic test.



Contact status on the contact surface
red is sticking contact, yellow is "near contact"
arrows indicate leaking surfaces.



Contact pressure on the contact surface
red indicates high pressure (50 – 100 MPa)
blu indicate very low pressure (0 – 2.5 MPa).

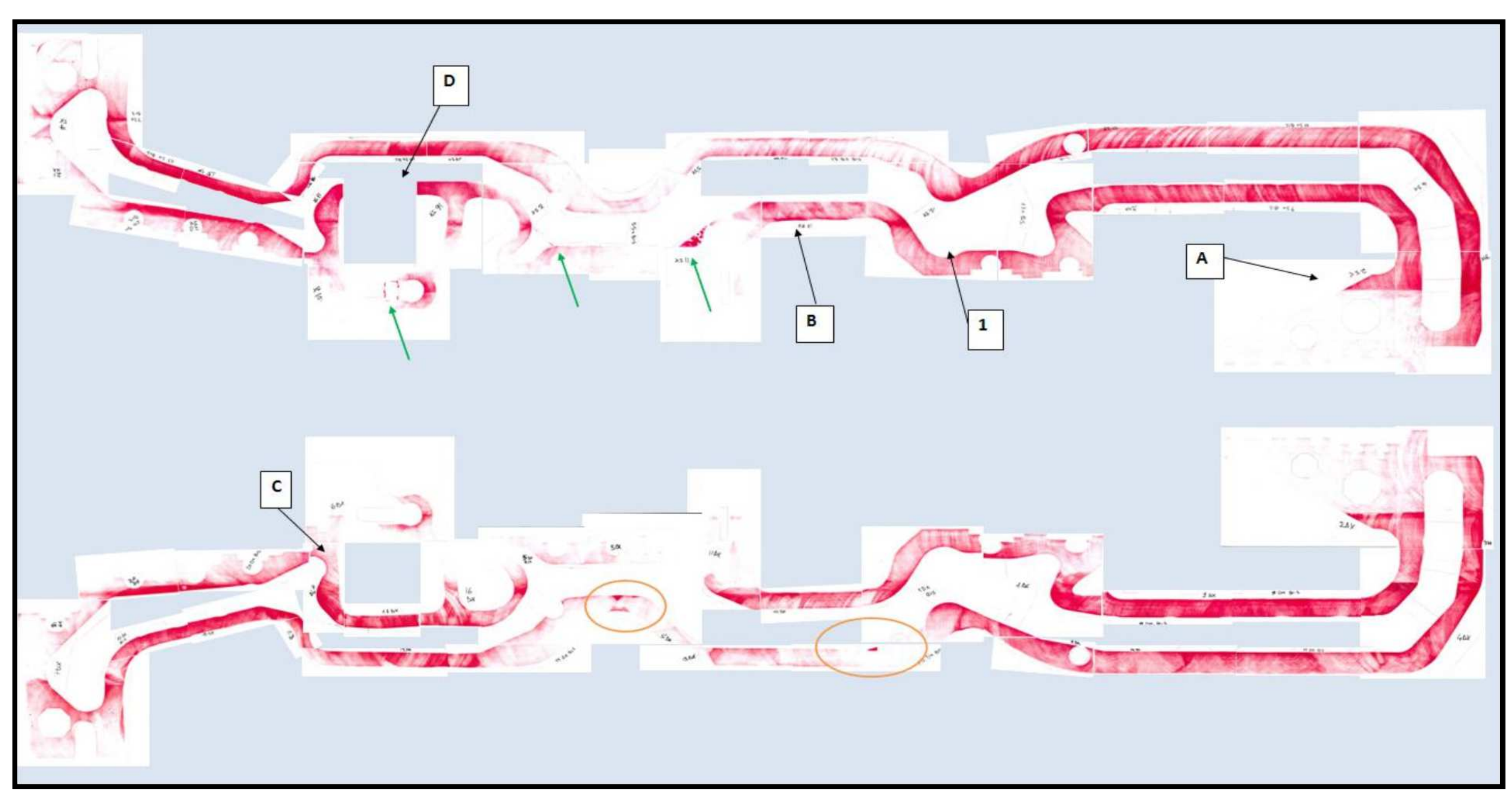
EXPERIMENTAL TESTS: in order to check the theoretical results, which do not take into account surface irregularities that are within specified tolerances, it was decided to perform a test as partial validation of the obtained numerical results. The contact surfaces were equipped with thin pressure sensitive films suitable for a pressure range of 10 to 50 MPa. The casing were closed and only 25% of the nominal load was applied to the bolts. It was obviously not possible to apply internal pressure.

Photo of flange equipped with films after test:
dark red indicates pressure equal or above 50 MPa
white indicates pressure equal or below 10 MPa.

Deformation of casing and contact surfaces were different from full load calculated case. A simulation with reduced load on bolts and no internal pressure allowed to compare calculated and measured results. Basically the test confirmed very low or zero contact pressures in the identified critical regions. In some other parts also 0 pressure has been found: these were attributed to the combined effect of low applied load and some surface irregularities that were confirmed by accurate measurements (although within tolerances).

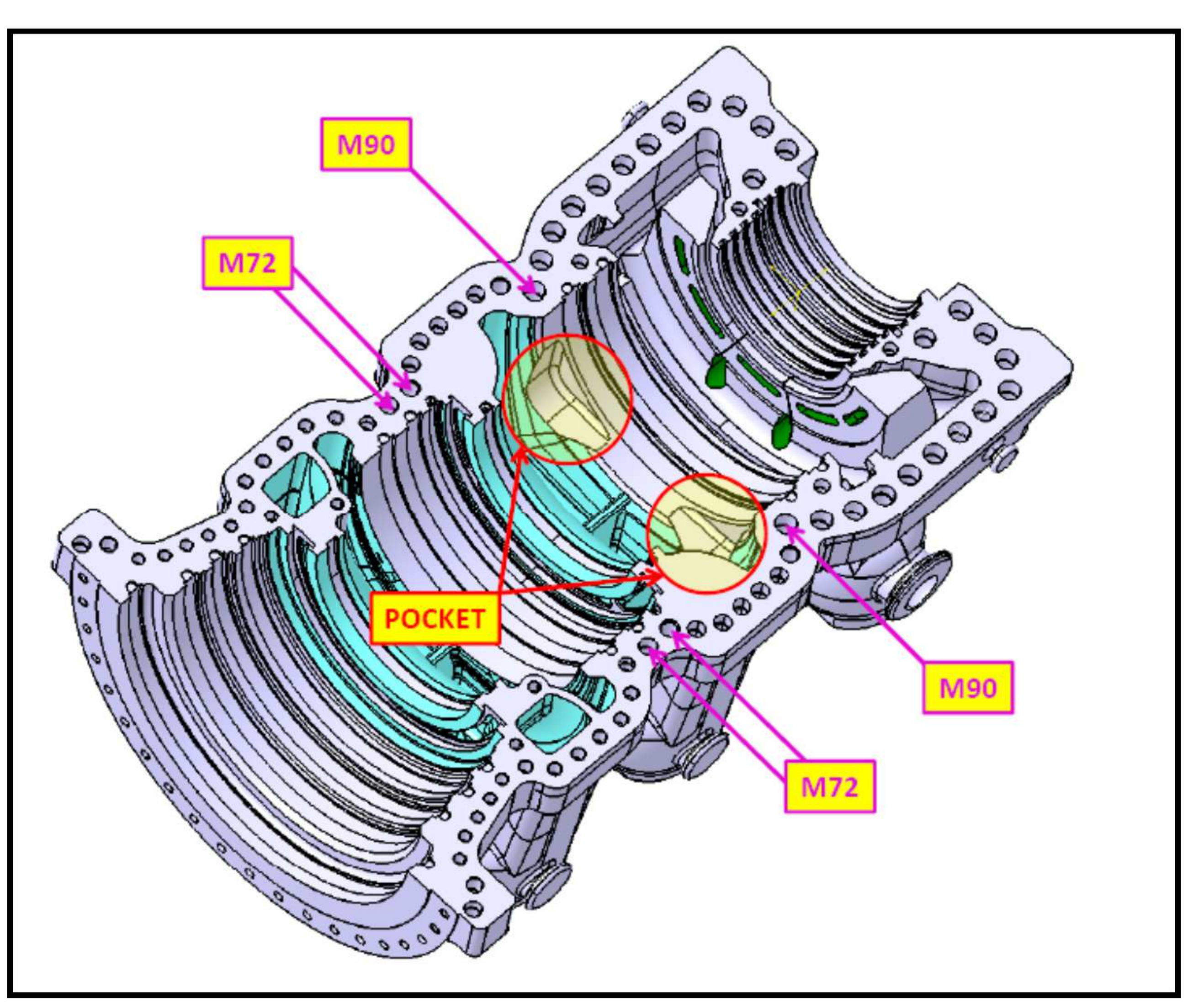
The next step was to simulate some modification in the design in order to overcome the problem. Load on some bolts could be increased but that measure alone was insufficient. It seemed that the connection between wall of the casing and flange was too stiff. Increasing the flexibility of the wall would allow the flange to deflect more under the load of the bolts.

These modifications have been introduced in the model and its effects have been simulated

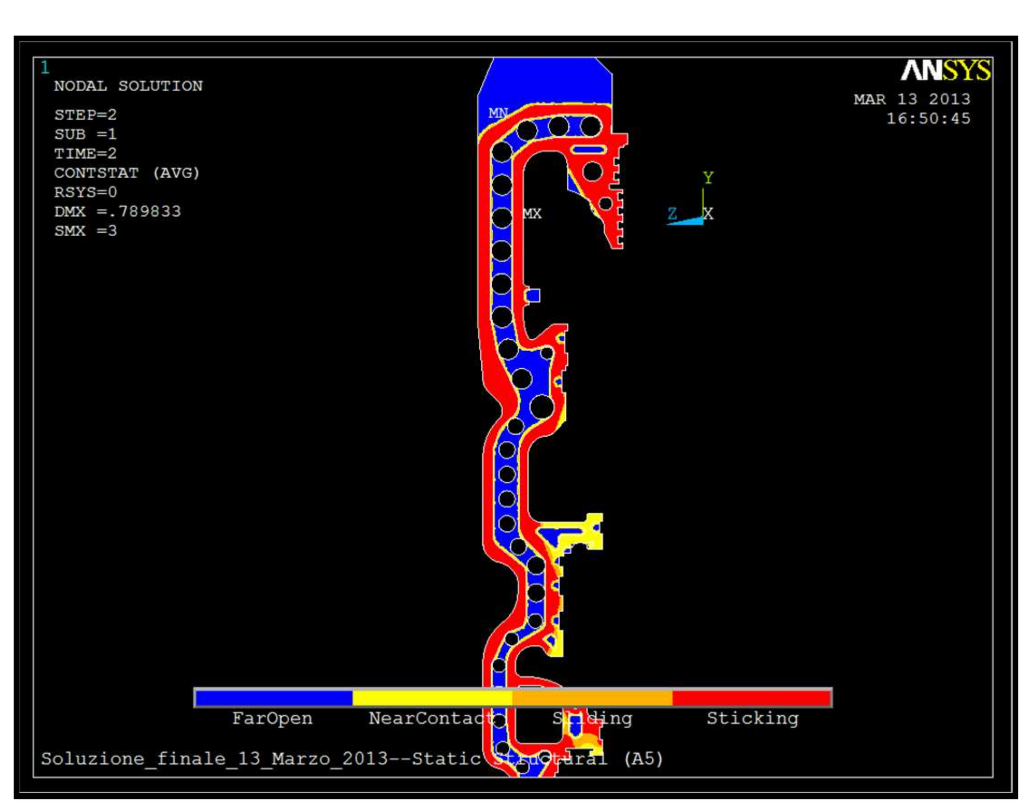


Scan of all films ricomposed after removal from flange. Green arrows indicate critical points in accordance with simulation where leakage could occur. D indicates a missing film. Other marks indicate parts where unexpected contact pressures were found, due to surface irregularities and unsufficient load on bolts: in A pressure is below 10 MPa, in B pressure exceeds simulated values.

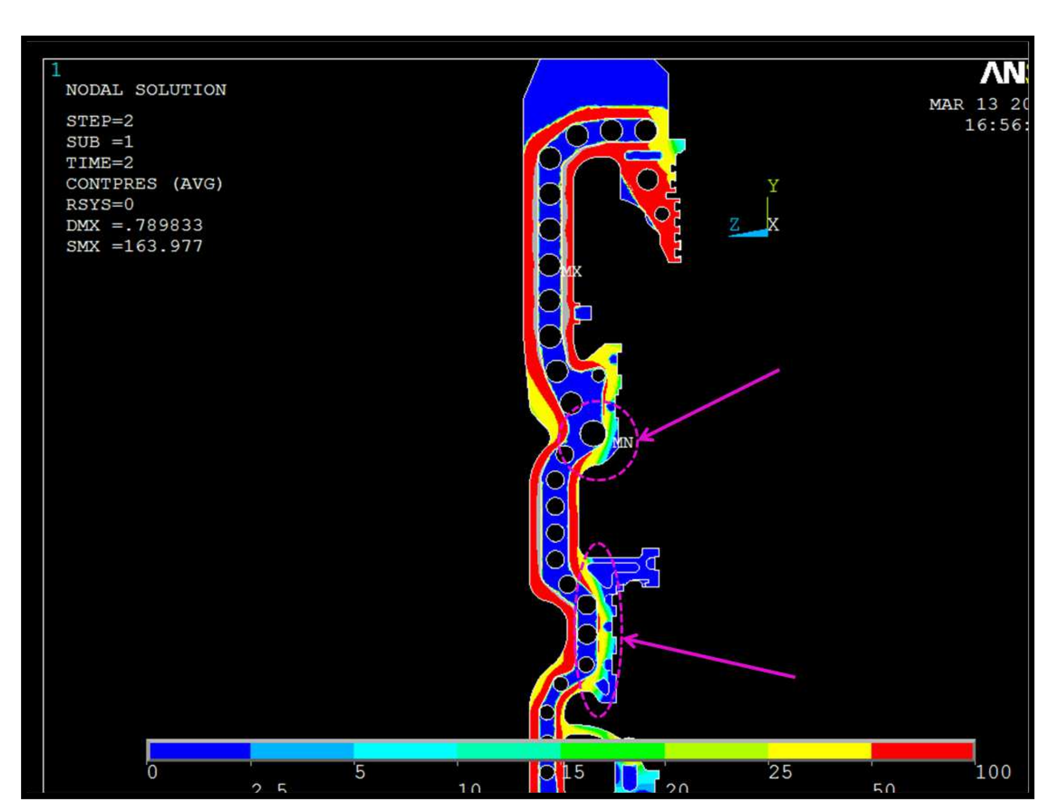
Some bolts in the critical points have been substituted by bolts of bigger size. In order to increase the local flexibility of the flange without reducing its thickness it was necessary to reduce the thickness of the wall at the inside of the casing as close as possible to the flange. The effect of machining of two internal pockets in the casing was simulated with the model, and dimensions, shape and position have been optimized for getting the desired flexibility and avoiding stress concentration. The pockets will allow the complete closure of the flange under the action of the bolts. The simulation shows the final results as contact status and pressure distribution, under the action of the internal pressure and the nominal load on the bolts. These solutions have been adopted, and the successful hydraulic test validated the simulated results.



Sketch of the casing with indication of the suggested modifications:
Size of some bolts has been increased (for increasing preloads)
Two pockets (that have negligeable influence on fluidynamic behaviour) have been introduced in the casing for increasing its local flexibility.



Contact status after specified modifications: red indicates sticking contact which is now present also in the critical areas.



Pressure distribution after specified modifications: pressures above 20 MPa (in yellow and red) are present also in all critical points.

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