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Simulation Based Engineering & Sciences

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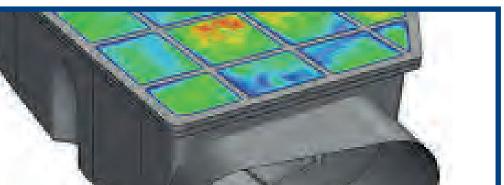

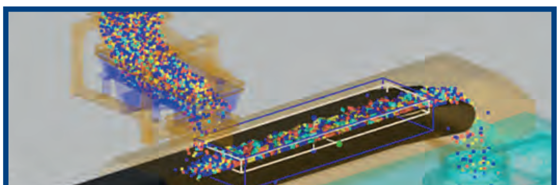

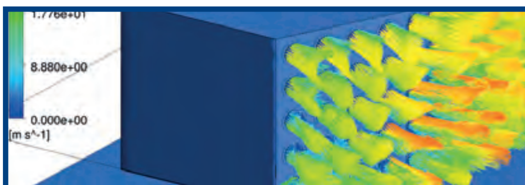

Lighter mechanical components using mesh morphing

Shape optimization is increasingly adopted in structural design. It allows to finely tune the parts getting products with better performances: accurate control of the stress level whilst keeping at the minimum the material usage and the weight. Reliable tools for addressing this discipline are one of the major needs of the industry fitting very well the modern trend of introducing additive manufacturing as a mainstream technology. An effective approach is provided by the use of mesh morphing as demonstrated in this paper adopting the FEA tool ANSYS Mechanical in conjunction with the ACT Extension RBF Morph.

Introduction

Shape optimization of structures is a well established topic, nevertheless its use in everyday structural design is emerging as a standard practice for the definition of a new component just in recent times. Among driving forces toward the massive use of shape optimization there are: the availability of High Performance Computing (powerful workstations and cloud resources), the high level of competition and the demanding market that needs better performances in less time, and the fast growing of new manufacturing processes based on 3D printing that allows the construction of complex shaped components not affordable for their complexity and cost when adopting standard processes.

Numerical tools based on Finite Element Analysis (FEA) are quickly growing to better fit aforementioned needs so that topological and shape optimizations are moving from the niche to the mainstream methods. One of the critical issues in the definition of automated optimization processes is the challenge posed by the efficient update of the computational grid; and this task becomes more and more complex because of the large nodes count reached when high fidelity models are used. It's quite common to use FEA models comprised of millions of nodes. Standard workflows rely on the generation of a new mesh for each shape variation which is updated according to the input parameters of the CAD. This is a very flexible approach that suffers of two main drawbacks: the parameterization of a complex CAD assembly could be quite a long and difficult task; the robustness is not that high as the regeneration of complex and unstructured meshes can fail and/or comes with the re-meshing noise (it means that the effect of the mesh dependence can be similar to the effect of varied parameter). New technologies based on direct modeling (as ANSYS Space Claim) or on mesh morphing allow to overtake the limitations of the standard process. Mesh morphing allows to update the mesh keeping exactly the same topology just updating nodal positions so that the new shape can be accommodated adapting the baseline mesh.

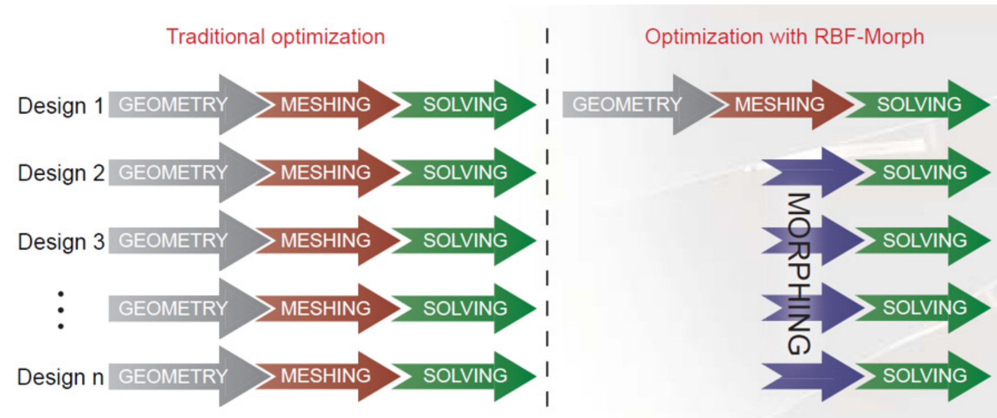

Figure 1- Comparison between a traditional optimization workflow and a mesh morphing based one

Mesh morphing as a shape parameterization tool

A comparison between a standard workflow and a mesh morphing based one is explained in Figure 1.

The applications proposed in this paper are developed exploiting the software RBF Morph ACT Extension which implements advanced mesh morphing based on the method of Radial Basis Functions (RBF) inside the FEM program ANSYS Mechanical. It's a new product released in 2015 and based on the technology of the ANSYS Fluent Add On available on the market since 2009 (www.rbf-morph.com). A study published by SACMI of Imola demonstrates how to integrate morphing and topological optimization tools. A further successful application by SACMI is demonstrated in Figure 2. Fatigue life optimization of a connecting rod of an internal combustion engine has been studied by the researchers of the University of Rome "Tor Vergata" and published at last AIAS congress. An effective application of mesh morphing has been adopted by Motocorse and is summarized in Figure 3 where the optimized shape of a motorbike racing part that combines style and performances is shown.

A typical workflow based on ANSYS Workbench is represented in Figure 4 where all the pieces required to set-up an optimization based on RBF Morph can be indentified: a parametric geometrical model (A), a structural analysis (B) that thanks to the morphing includes shape parameters, FEModeler (C) that is used to regenerate the final CAD of the optimal morphed shape, the parameters (Parameter Set), a DOE based response surface (D) and an optimizer linked to the response surface (E).

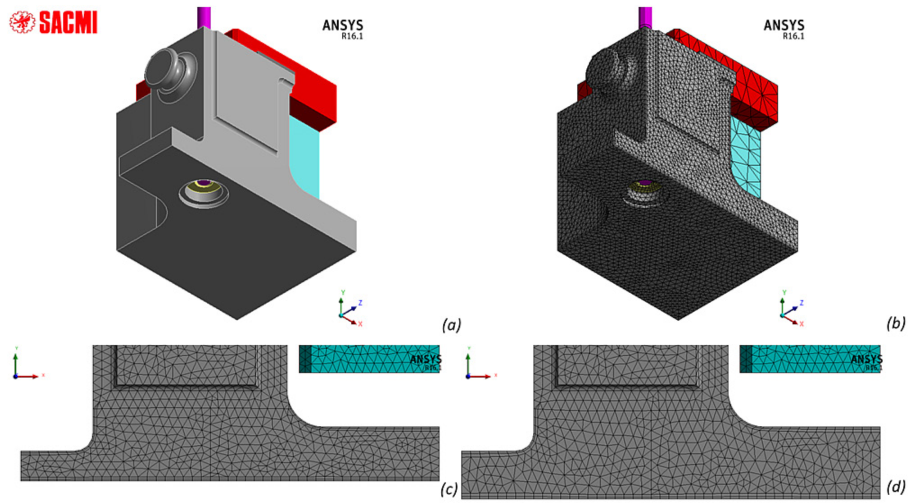

Figure 2 - Thanks to RBF Morph ACT Extension, SACMI performs mesh-based shape optimization within ANSYS Workbench overcoming parametric CAD-based shape optimization limits. In the example the thickness of the grey component is changed by preserving the contacts of the whole assembly

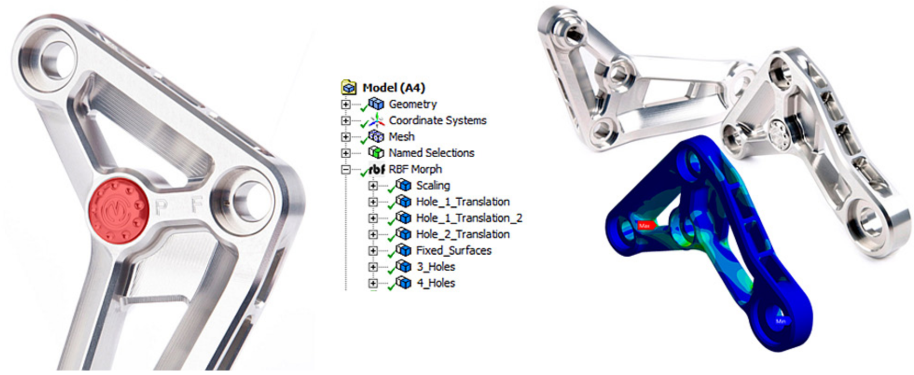

Figure 3 - The Republic of San Marino company Motocorse, with the support of the engineers A. Ridolfi and F. Giorgetti, has designed and optimized using ANSYS Mechanical and RBF Morph a CNC billet machined racing version of the rear suspension rocker for the motorbike Ducati 1199 Panigale

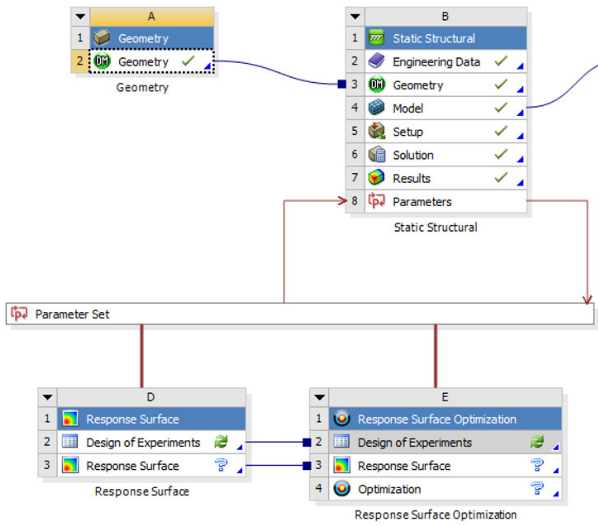

Figure 4 - Optimisation workflow in ANSYS Workbench. A geometrical model is used to generate the baseline (a static analysis in this example). Input parameters (that feed RBF Morph) and output parameters (computed by FEM solver) are steered by the optimization software DX (adopting in this case a response surface method). Optimal design point is sent to FEModeler that allows to generate the CAD of the new shape

Optimization of a wheel rim

To give a better insight about the proposed approach a detailed application, extracted from a paper published by D'Appolonia (RINA Group) in the proceedings of last CAE Conference in Italy, is given in this section and has as a target the reduction of the weight of a wheel rim while keeping the level of safety imposed by the testing standards applied in this field.

Baseline study foresees the modeling of the rim represented as a solid. The geometry is repeated cyclically eight times but boundary conditions are not cyclic and so the full

model is required. All the loading conditions are simplified in static ones, and are defined with the aim to reproduce virtually the experimental testing cycle defined according to the TÜV standard. According to the standard, fatigue strength has to be considered and each of the load case produces as output a failure index that accounts for load repetitions and relevant strength assessment criteria.
The workflow defined in Workbench allows to solve all the load cases within the update of a single design point and retrieve as output all the failure indexes, the part mass and the part moment of inertia about the wheel axis. The rim is made in Aluminium alloy AlSi7Mg, material data are summarized in Table 1. Boundary conditions are sketched in Figure 5; the experimental testing cycle is conducted constraining the rim and loading the hub with an alternating tilting moment (two levels of intensity: ABM 50%, ABM 75%), an alternating torque (AT) and a vertical load representing the car weight acting on a single wheel (CW). For each loading conditions allowable fatigue strength are computed and then composed with resulting stress to obtain a failure index.

Property	E (MPa)	ν (-)	S_y (MPa)	S_u (MPa)	S_F (MPa)	ρ (kg m^{-3})
Value	$71 \cdot 10^3$	0.33	280	314	89	2770

Table 1 - Material data of the Aluminium alloy used for the manufacturing of the rim

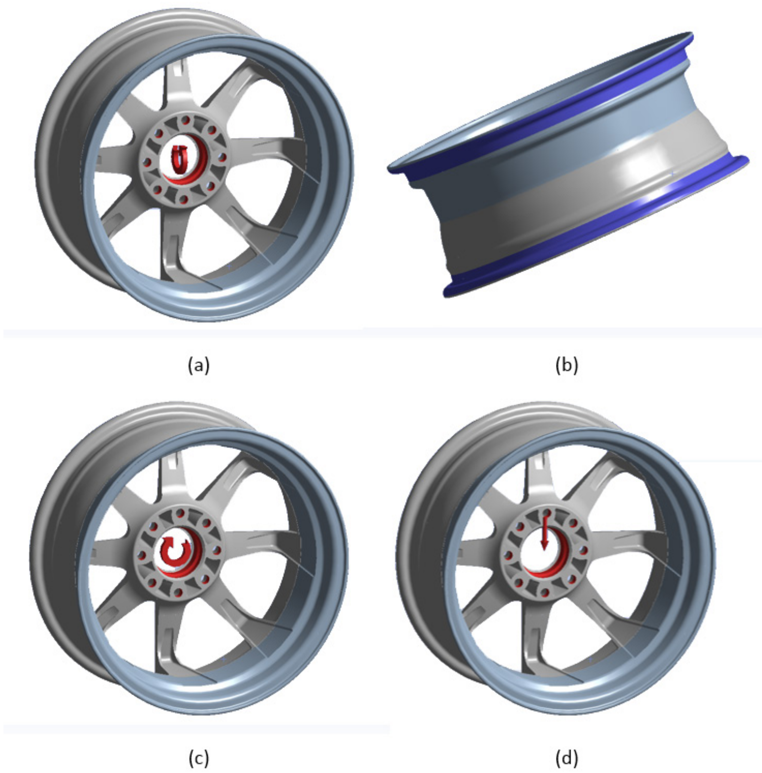

Figure 5 - The wheel is loaded using an alternate bending moment (a), an alternate torque (c), a load representing the car weight (d). Loads are introduced acting on the surfaces that connect the rim to the hub. The wheel is constrained at the interface with the tyre (b)

Mesh morphing is adopted to understand if a lighter shape of the spokes, obtained by a scaling operation of the spoke itself with respect to its transversal symmetry plane, is feasible. RBF Morph set-up foresees to control individually each spoke getting eight shape parameters. Such parameters are reduced to a single one imposing even constraint equations in Workbench.
Set-up is demonstrated in Figure 6 where it's clear how the morpher acts in the tree just after the mesh generation and Named Selections definition. In this example all the nodes of the mesh are used as target for the morphing action (wheel-rim); the shape is controlled acting individually on the shape of each spoke by a scaling operation (spoke1-scaling, spoke2-scaling,…,spoke8-scaling), keeping fixed the nodes of the hub and of the body of the rim (fixed-holes, fixed-external-surfaces) and leaving the remaining nodes free to be deformed by the morphing action adopting a linear RBF. A detail of how the nodes of a single spoke are controlled is represented in Figure 7 where the preview tool is used to check the correctness of set-up during its definition.

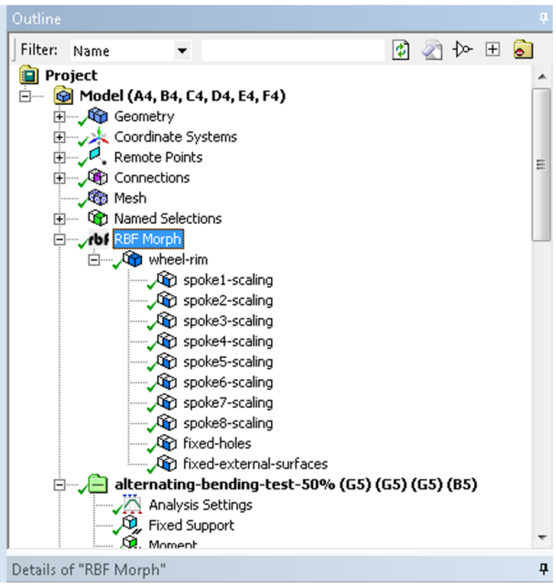

Figure 6 - A detail of the Tree in Mechanical; RBF Module acts just before the mesh generation and the definition of the Named Selections. It's comprised of a set of target nodes (wheel-rim), of 8 set of source nodes controlled by a scaling (spoke1-scaling, spoke2-scaling,…,spoke-8-scaling) and of two set of fixed nodes (fixed-holes, fixed-external-surfaces)

Table 2 summarizes the values of the parameter computed as a function of the shape parameters. It's worth to notice that the update of the Design Points with parametric shape is fully automated. According to the Workbench standard, new design variables (input and output) can be exposed in WB simply checking with a P the desired fields, including the input within the set up tree of RBF Morph. Such automation can be controlled by means of the optimizer that comes with Workbench, or by means of external software as modeFrontier in the study conducted by SACMI.
For the wheel rim studied the best material exploitation is obtained adopting a scale factor equal to 0.72 (Table 2) which leads to a weight reduction of about 0.5kg (-6.6%) whilst guarantying the safety levels required by the TUV standard. Stress levels of the original and the optimized solution are compared in Figure 8.
In this study a parametric CAD was not available and so the completion of the workflow requires the generation of a new one using a back2cad process. FE Modeler allows to get the geometry represented in Figure

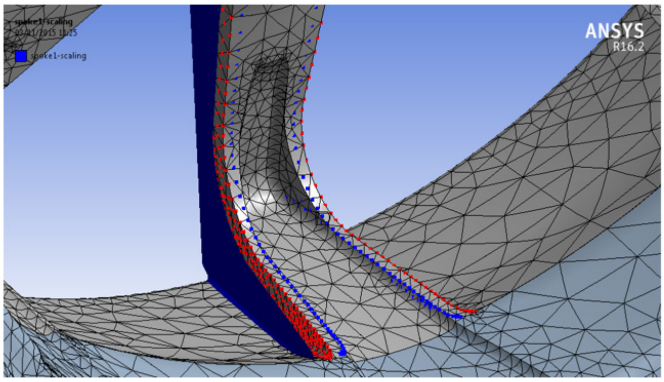

Figure 7 - Detail of RBF set-up used to control the shape of one of the spokes (spoke1-scaling); red points represent the node used as source points in the original position, blue points represent their preview in deformed position

TÜV test	ABM 50%	ABM 75%	AT	CW
FI scaling 0.8	0.75	0.91	0.33	0.31
FI scaling 0.7	0.83	1.19	0.41	0.39
FI scaling 0.72	0.82	0.99	0.39	0.34

Table 2 - Failure Indexes of the four load conditions are computed as a function of the scaling parameter that control the shape of the eight spokes

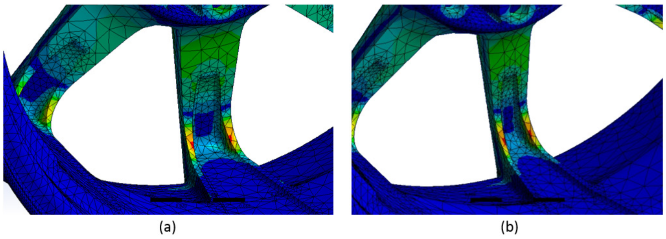

Figure 8 - Comparison of stress level between the original FEM model (a) and the optimized one (b); the new shape allows to reduce the weight getting a better exploitation of the material

9. It's important to highlight that such process is facilitated because the topology is preserved and surface reconstruction can be driven generating automatic selection which associates the new mesh with baseline geometry. The result is a new CAD that maintains the same topology of the original one (same face count).

Conclusions

Presented study shows how shape improvements of a component are feasible in a very short time adopting mesh morphing. The great flexibility of Workbench makes feasible several scenario that are relevant for the designer perspective. Validated legacy models (often available as dead meshes) can be updated to account for small updates decided during the service of the component without the need (and the high related cost) of generating a new mesh. Auxiliary CAD models of the area to be updated can be used as targets; a new shape can be easily introduced and if the target is parametric (for instance introducing control parameters in Design Modeler) an hybrid workflow, in which the geometry is controlled by the CAD and the mesh update by the morpher, is possible.

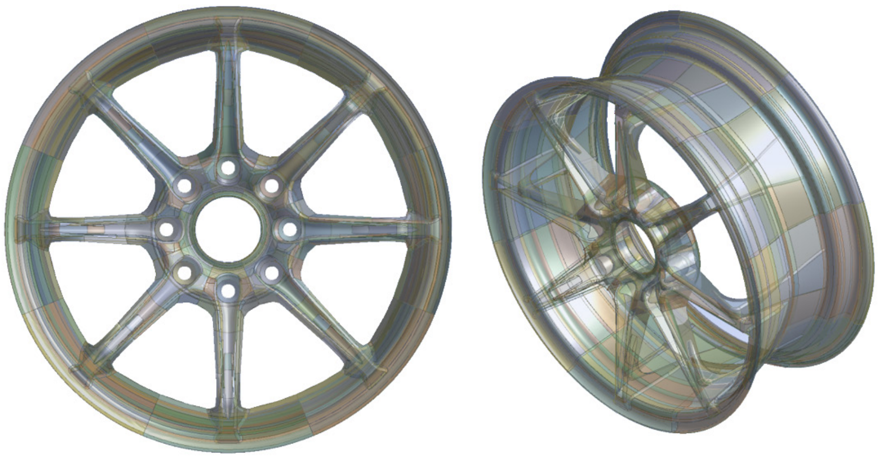

Figure 9 - The new CAD model obtained starting from the optimized mesh

The morpher offers an high flexibility and the basic shape modifications (Translation, Rotation, Scaling, Curve Offset, Surface Offset, Curve Target, Surface Target) can be chained together to define new ones. For the introduction of new advanced feature the user can also customize RBF Morph with an ACT Extension that can override the displacement field of the source points contained in a node of the Tree. Such functionality has been used to drive the shape directly with mesh output: a surface can be sculpted according to stress levels; a crack can be extended according to local values of fracture parameters.

The great potential of the high performance RBF solver that is under the hood of RBF Morph software line is not yet fully discovered because of the novelty of the approach and the youngness of the product. It is worth to highlight that major steps toward the development of this technology have been driven by specific industrial needs. The developing team of RBF Morph is active in many research and industrial projects and is open to cooperate for overtaking new challenges.

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University of Rome – Department of Enterprise Engineering "Mario Lucertini"

The new RBF Morph ACT Extension for ANSYS Mechanical is now available on the ANSYS App Store.

After the success gained within ANSYS market by the commercial mesh morphing solution for CFD models, RBF Morph ANSYS Fluent Add-on, RBF Morph team has developed a new software, based on the same technology, for the users of ANSYS Mechanical.

RBF Morph ACT Extension, developed with the Application Customization Toolkit (ACT) of ANSYS, is a software fully embedded in the GUI of ANSYS Mechanical and allows to make a model parametric just in a few clicks.

RBF Morph ACT Extension is distributed by RBF Morph (www.rbf-morph.com). A free trial, with limited features, is available for direct download on the ANSYS App Store.

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