

CONNECTING ROD OPTIMIZATION INTEGRATING MODEFRONTIER WITH FEMFAT

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ABSTRACT –

This paper describes the integration of the multi-objective optimization software modeFRONTIER from ESTECO with ANSA mesh morphing and μ ETA post processor, illustrating an application to a fatigue analysis case of industrial relevance.

In modeFRONTIER environment, any CAE software can be easily integrated in the process flow through the available direct interface nodes, including ANSA and μ ETA, allowing the automatic update of parameters and execution of the CAE simulations.

The available multi-objective optimization algorithms (including Game Theory MOGT, Genetic Algorithm MOGA-II and FAST algorithms - based on Genetic Algorithm and Response Surfaces) can be used to drive the automatic simulations until the optimal design solutions are found, accordingly to the specified objectives. In addition, several tools for pre, post and statistical analysis are available in order to support the engineers in the complete design process.

In this paper an application of modeFRONTIER combined with ANSA and μ ETA for the optimization of a diesel engine connecting rod is illustrated. The mechanical component comes from BMW-Motoren, and the objective of the optimization is the mass minimization with the satisfaction of prescribed safety factors (fatigue analysis with FEMFAT software).

TECHNICAL PAPER -

1. INTRODUCTION

Multi-objective optimization in an automatic and distributed environment, that allows direct communication between multi-disciplinary simulation software, is more and more becoming a key factor in today's design process.

Traditional design approach ('trial and error') usually requires many attempts to the designers, which every time need to modify their numerical models by hand and run several solvers, especially when it is difficult to know a priori in which direction of the multi-dimensional variables space to move in order to find the best solutions.

Conversely, the multi-objective design environment modeFRONTIER [1] allows to integrate different computational software (any commercial or in-house code) into a common design environment, thus allowing the automatic execution of a series of designs proposed by a selected optimization algorithm, until the specified objectives are satisfied.

In this modular environment, each component of the optimization process, including input variables, input files, scripts or direct interfaces to run the software, output files, output variables and objectives, is defined as a node to be connected with the other components.

In this scenario, the ANSA and μ ETA [2] direct interfaces available in modeFRONTIER play an important role for designers, since all the morphing parameters and responses defined in the model can be automatically recognized by the direct interfaces.

In this way, the complete logic flow from parameterization to performance evaluation is defined by the user who can select among several available optimization algorithms accordingly to the objectives defined. These include, Genetic Algorithms [3], Evolutionary Algorithms, Game Strategies [4], Gradient-based Methodologies, Response Surfaces (used to speed up the convergence of optimization and to approximate the response of the system made by the available Meta-Models), and Robust Design Optimization (optimization under uncertainties on input parameters).

Statistical and Multi-Variate Analysis tools [5] can be applied to find important information about the influence of the parameters in the system, to address problems characterized by a large number of parameters and heavy computational efforts with the highest efficiency.

In the automotive industry, and in particular in the fatigue analysis of engine components, an optimization procedure is strategic to achieve important improvements to specific model characteristics. In this paper the connecting rod of a diesel engine, provided by BMW-Motoren, is optimized in order to reduce the mass, keeping satisfied the constraints on admissible contact stress and admissible fatigue safety factors.

2. Safety Analysis: Problem description and parameterization options with ANSA

The object of the optimization problem proposed in this paper is a diesel engine connecting rod, produced by BMW-Motoren (fig.1). The goal is to modify the shape of the actual conrod in order to minimize the mass, but keeping satisfied 4 constraints, and in particular:

- Max pressure on big eye < limit
- Max pressure on small eye < limit
- Min Safety Factor on shaft > limit
- Min Safety factor on pin > limit

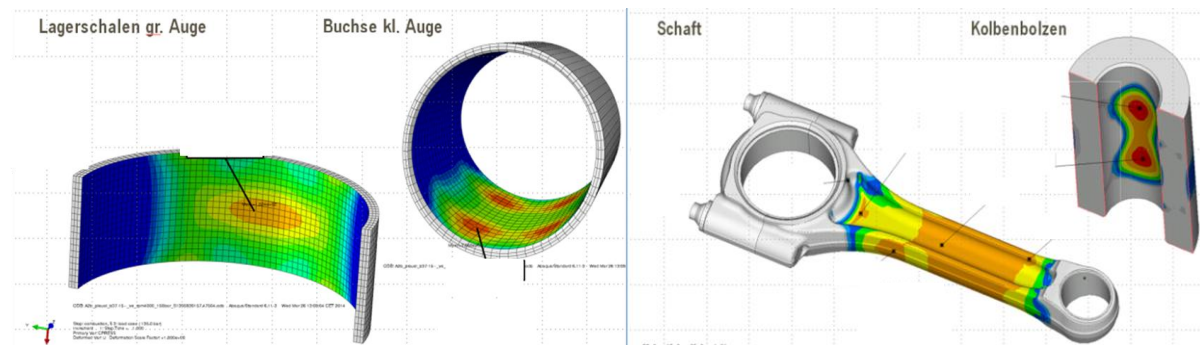


Figure 1- Connecting rod: constraints on eyes stress (left); safety factors on shaft/pin (right)

The definition of the performances above require the simulation of combustion+inertial loads through the ABAQUS software (fig.1 left), and the further simulation of fatigue analysis through FEMFAT software (fig.1 right).

In order to define an optimization procedure, it is necessary first of all to parameterize the geometry of the conrod, defining an accurate meshing procedure in ANSA. In particular, the most sensitive parts to be controlled are the shape of the cut of the shaft, its depth, and the radius and shape of the fillets connecting the shaft with the eyes, which are generally accumulators of stress.

For the parameterization purpose, two approaches can be applicable combining modeFRONTIER with ANSA.

The first one consists in the CAD parameterization of the conrod, for instance using CATIA v5, and then in using a standard script (in C language) for ANSA, which allows the automatic re-generation of the mesh for each updated geometry, following the rules defined for each meshing scenario in the ANSA model that can guarantee the required mesh quality (for instance, a finer seed can be defined for some regions – meshing scenarios, and a coarser one for others, specifying in all the cases the required mesh quality controls).

The second approach, which is fully described in chapter 3, consists in the definition of morphing blocks in ANSA model, which can be controlled by some control points. By the variation of these control points, the mesh is automatically modified together with the geometry, so the regeneration of the mesh is not needed in this case.

Both approaches are available in modeFRONTIER, through the direct interfaces to CAD software in the first case, and through the direct interface with ANSA morphing in the second case. The first approach can be followed for instance when large geometrical variations are required, while the second approach offers the advantage of not re-generating the mesh for each design, which can save an important amount of time in an optimization process.

3. Workflow creation in modeFRONTIER and usage of ANSA/μETA direct interface

The next step needed to setup the optimization process is to define the process workflow in modeFRONTIER (fig.2), which looks as like as a modular network connecting the different “bricks” of the process design.

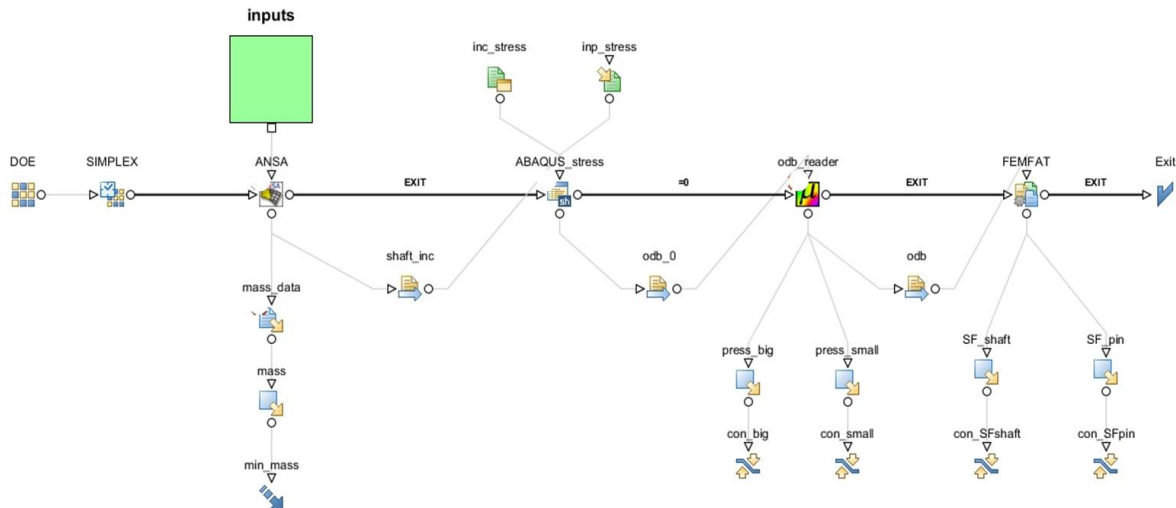


Figure 2- modeFRONTIER workflow for fatigue safety factor optimization

All the parameters which control the shape of the conrod are defined by dedicated input nodes (inside the green subsystem of fig.2), which specify their range of variation. The ANSA model including the original mesh can be automatically updated for each different configuration proposed by the optimization algorithm (for this application, a single-objective SIMPLEX [8]) accordingly to the values of the input variables, and the updated mesh model (.inp file) is then transferred to the following application, a shell script which launches the Abaqus simulation for the stress analysis.

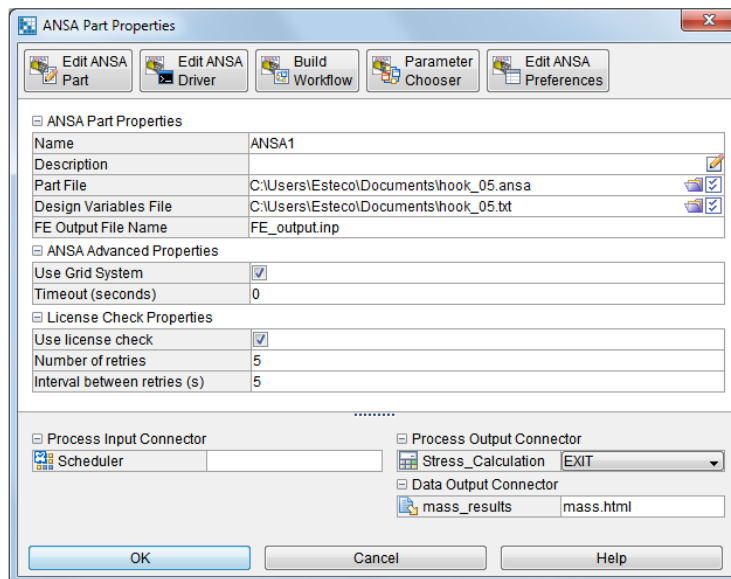


Figure 3 – Example of modeFRONTIER direct interface for ANSA

About the ANSA direct interface (fig.3), the user has just to indicate the ANSA model file name, the ANSA Design Variable File as defined in the Optimization task (DV file), and the name of the output file to be saved by the ANSA model (in our case, export for ABAQUS). At that point, all the morphing variables defined in the ANSA model are automatically introspected by the node, and (by using the Parameter Chooser tool) it is possible to link each one of them to a proper design variable node defined in modeFRONTIER workflow. The ABAQUS simulation is then automatically repeated for each model proposed by the optimization, accordingly to the instructions defined in the .inp file produced by ANSA. The stress results needed to define the constraints on the big and small eyes of the conrod are instead obtained by the direct interface of mF with μ ETA (fig.4), which automatically list all the available responses of the selected model (in this case the .odb file containing the results of the ABAQUS analysis), and allow the user to select the needed response to be linked to the corresponding objective/constraint of the mF workflow (Parameter chooser tool).

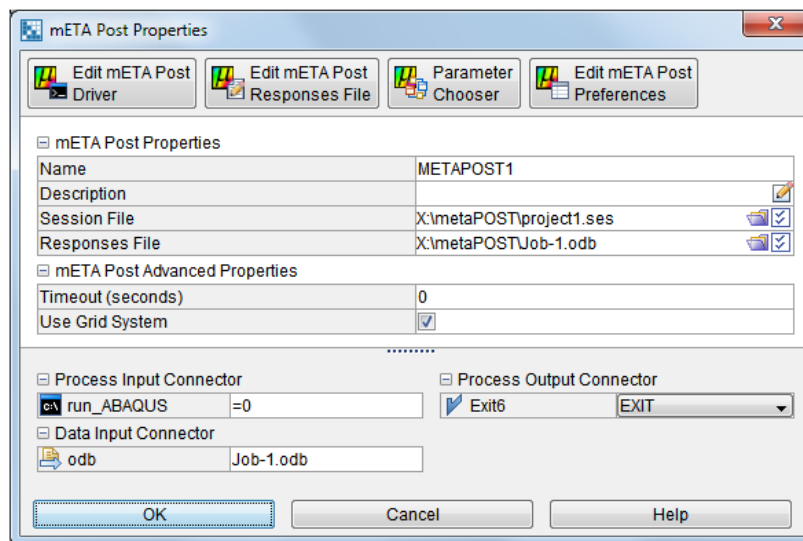


Figure 4 – Example of μ ETA node in modeFRONTIER

The final part of the process workflow then includes the direct interface to execute FEMFAT simulations, accordingly to the specified project file (which define which outputs are needed to extract) and to the model results file (the .odb file containing the results from ABAQUS). All the needed responses (from FEMFAT and for μ ETA) are then connected to the corresponding objectives/constraints nodes, completing in this way the optimization workflow. The optimization process is at this point ready to be executed, launching automatically each simulation required by the optimization algorithm.

4. Usage of modeFRONTIER GRID for distributed remote applications

modeFRONTIER allows the possibility to activate the GRID tool [6], which can be used to distribute the simulations of each design (or at least of some application nodes, such as for instance the node which launches ABAQUS simulations) on any remote machine available in the network (fig.5).

Jobs are therefore assigned by the system to different grid nodes according to the load balancing policy, excluding nodes that are disabled or can't execute jobs, and therefore fully exploiting the available computational resources of the local network.

As a requirement, a common directory visible from all the nodes of the GRID needs to be mounted. Then the agent should be configured via Grid Manager on each machine that will enter into the GRID.

As soon as the GRID System is activated on each machine, the optimization can be launched by modeFRONTIER, applying the algorithm described in the next section.

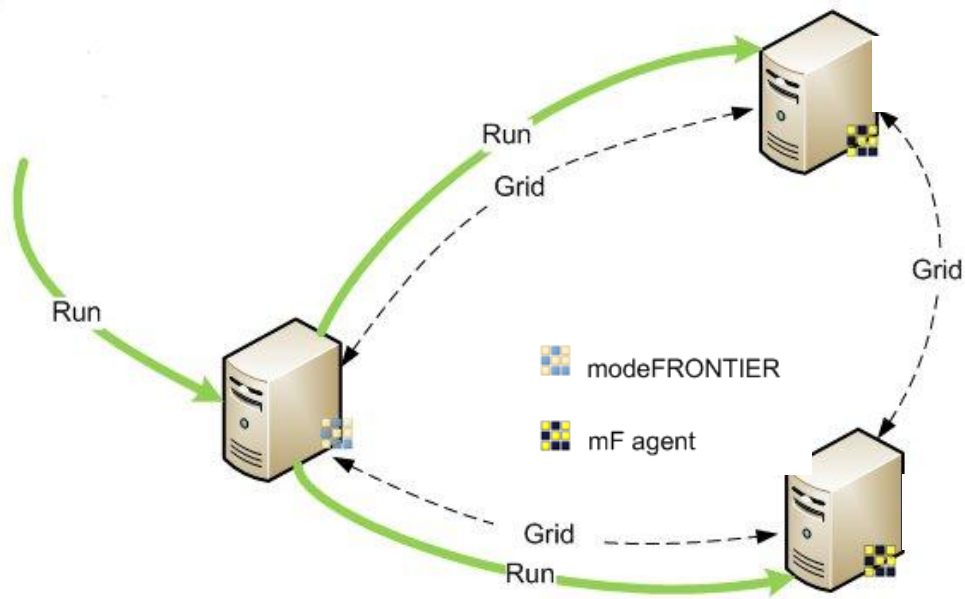


Figure 5 - GRID network launched by modeFRONTIER

5. Optimization results

The application of SIMPLEX algorithm [8] to the problem defined in this paper allowed to find the results reported in fig.6-7, with an overall number of required simulation designs less than 200. Through the usage of GRID system (chapter 4) it has been possible to reduce the overall optimization time by running the simulations on multi-processors (8 cpu), so the optimization could have been completed in about two weeks.

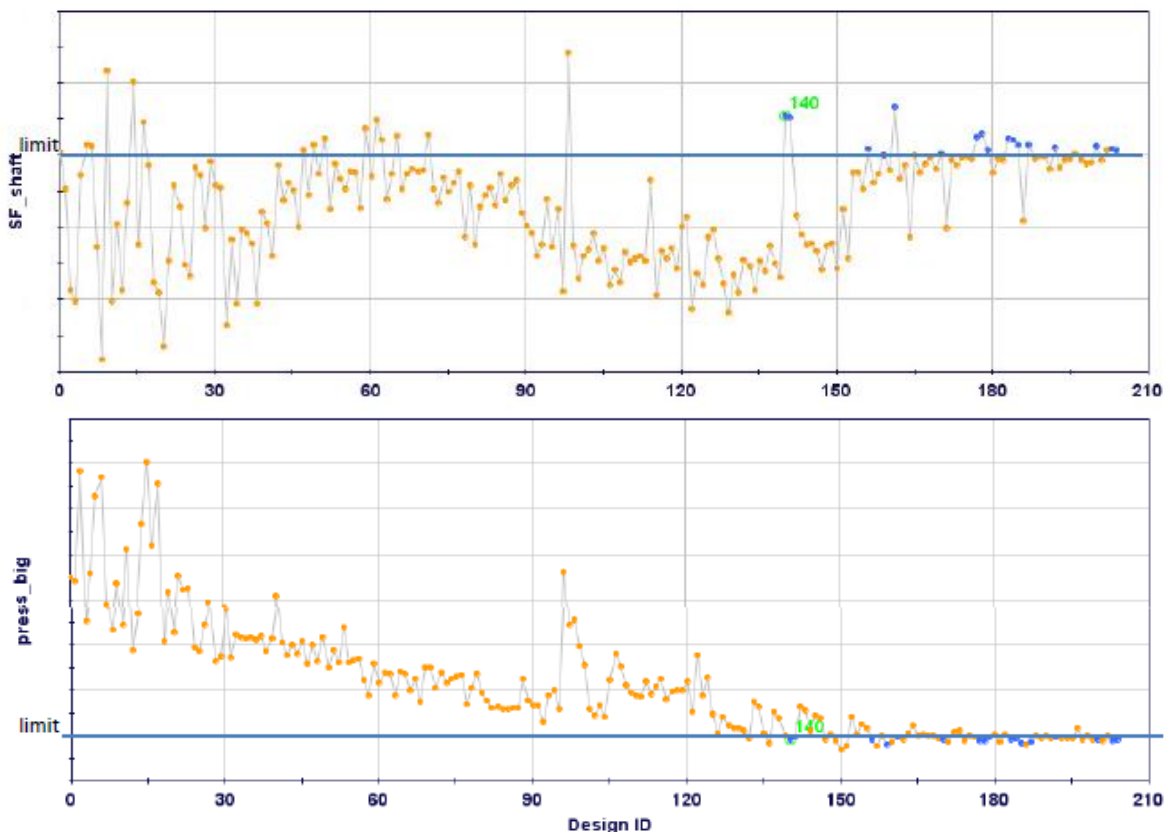


Figure 6 – Optimization results –Objectives convergence

The first charts (fig.6) reports the convergence chart of the objective functions, in this case more in particular the two constraints which have given more difficulties to be satisfied, i.e. the safety factor on the shaft (over the limit) and the pressure load on the big eye (below the limit).

In the chart the unfeasible designs (which do not respect the constraints) are indicated by a yellow point, while the feasible designs (which respect all the constraints) are indicated by a blue point. It is possible to note that only in the last part of the optimization all the constraints have been satisfied.

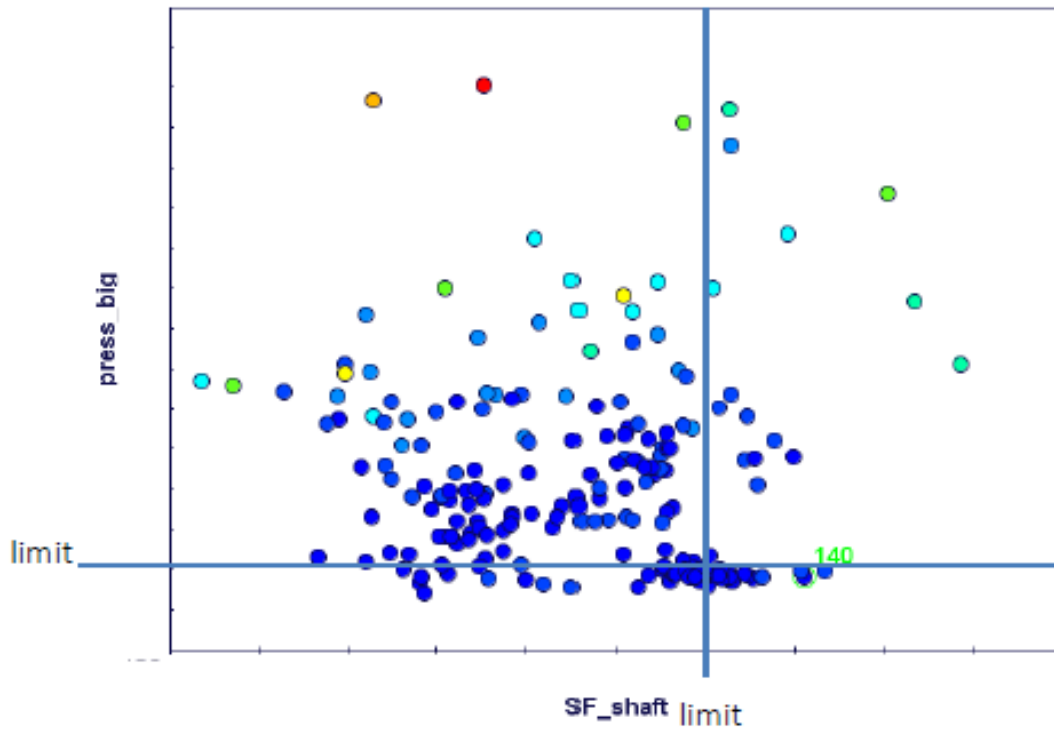


Figure 7 – Optimization results – Pareto chart

Figure 7 illustrates then a scatter chart reporting the two constraints in abscissa and ordinates, for each design proposed by the algorithm which is represented by a bubble. The colour scale of the bubbles represents the value of the objective, the mass, which is to be minimized, so the blue points are to be preferred because they have lowest values of mass.

From the feasible designs, the best one which has been selected as final design, is the one highlighted in green (ID 140).

Table 1 below reports the improvements achieved for the optimal conrod configuration: all the constraints limits are respected, with a significant reduction of the big eye pressure (11%), and a reduction of 5% of the overall conrod mass.

Table 1 – Optimal configuration performances with respect to baseline

	Press big_eye	Press small_eye	SF shaft	SF pin	Mass
Optimized configuration	-11%	<limit	> limit	> limit	-5%

6. Conclusions

This paper has illustrated how to integrate ANSA and μ ETA software in the multi-objective optimization environment modeFRONTIER, through the dedicated direct interfaces, and how to set up and run a multi-objective optimization for an application of mechanical fatigue analysis.

Several tools available in modeFRONTIER have been used for this optimization: ANSA and μ ETA nodes (respectively to generate the updated model and to extract the result from the stress analysis), script nodes to launch the suitable solver for the simulation (ABAQUS and FEMFAT), optimization algorithms to optimize the model respecting the given constraint, and the GRID tool to distribute the simulations on a set of specified remote machines available in the network.

The optimized solution had significantly improved the baseline configuration, and has been obtained by a small overall number of simulation designs.

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