Title:
A Model-Based Simulation Approach to Support the Product Configuration and Optimization of Gas Turbine Ducts

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Keywords:
Product Configuration, Product Optimization, Model-Based simulation, Virtual Prototyping, oil & gas

DOI: 10.14733/cadconfP.2017.258-262

Introduction:
Nowadays, product configuration and optimization are very important topics in several industrial applications such as the manufacturing of Engineered-to-order (ETO) products [5], where there is a fierce increase in market competition [8]. Generally, the enterprises, which develop ETO products, gradually focus competition on how to increase the external variety of products to meet customers' individual requirements under time and cost constraints by decreasing the internal variety of products, thus realizing the maximization of enterprise profit [8, 9]. The bottleneck issue regards how to satisfy the personalized customer requirements under the current production conditions and cost constraints.

Product configuration solutions are generally derived from configuration-oriented product models by the knowledge or constraint-based methods; however, there are problems like combination explosion and difficulty of multi-objective optimization [6]. A solution was analyzed by Li et al [6] which proposed a multi-objective optimization method of production configuration, based on multi-object genetic algorithms. They confirm that a configuration-oriented model is necessary to describe the composition of the components' relationship in a product. Their approach works well for assemble-to-order (ATO) products like personal computers; however, it needs integration to be applied for ETO products, such gas turbine ducts or steel structures. While ATO products are modularized and components are standardized [9], ETO products also require technical analysis to be included in the optimization loop to support the engineering phase. Willner et al. proposed a model for analyzing and improving design automation activities in ETO companies such as the use of sales-configurator and technical configurator.

Typical ETO products are oil & gas systems, which are designed and customized on the basis of the client's requirements [1]. Generally, the manufacturing of complex ETO products is characterized by a negotiation phase [6, 9], where a customer deals with different manufacturers, in order to choose the best partner for the product fabrication in terms of cost, results, and timeline. Therefore, it is very important for the producer to approve and deliver a project quote as soon as possible, according to the customer timeline and specifications. On the other hand, a quote needs a preliminary design and a technical analysis of feasibility. These studies begin within the negotiation phase, involving the procurement office, and continue inside the technical offices until the negotiation is final. Thus, there is a necessity to reduce the time of each early design phase, increasing efficiency and optimizing cost and performance of the product. As a solution, some industrial players have been paying attention to design tools and methods which support the engineers in the reduction of cost and time [2, 3, 4]. One of these solutions is the development of configuration tools [5], which allow past design solutions to be reused and new product variants to be defined and pre-designed. However, the delivery of new configurations of products requires a technical feasibility analysis before closing the contract of the order with the customer. The other solution to reduce cost and time is the use of a multi-objective optimization (MOO) analysis [2, 6]. Generally, objectives of MOO analyses are focused on the searching of configurations which maximize the product performance and minimize weight and manufacturing cost. Wei et al. presented a multi-objective optimization of a modular product configuration [7] to support the search of feasible solutions that satisfy customer requirements and product constraints. This research is based on genetic algorithms (GA); however, they do not consider numerical simulations into the optimization loop.

There is a lack of commercial tools which can support the designer from the early configuration phase to the product optimization with the automatic generation of geometric models and simulations. While traditional software tools can be used for the product configuration, with automation in the CAD modelling, other ones can combine optimization algorithms with numerical simulations. However, the combination of all these design levels requires the development of a dedicated platform tools.

The research aims to reduce time and cost related to the early design phase of an oil & gas system, focusing on gas turbine ducts. The paper proposes a methodological approach to integrate the design optimization with the product configuration using Model-Based simulations to verify the technical feasibility and to optimize the product design. As a test case, the early design of a gas turbine chimney is proposed.

Main Idea:

The proposed method has been tested with the configuration and optimization of a gas turbine chimney. Fig. 1 describes the methodological approach, where the Model-Based simulation is the connection point from the configuration phase and the optimization one. The product configuration requires the definition of the input specifications, the selection of the boundary conditions, and the setting of the functional and geometric parameters. The output of the proposed configuration process is the automatic generation of a parametric product BOM and CAD-models with optimized parameters.

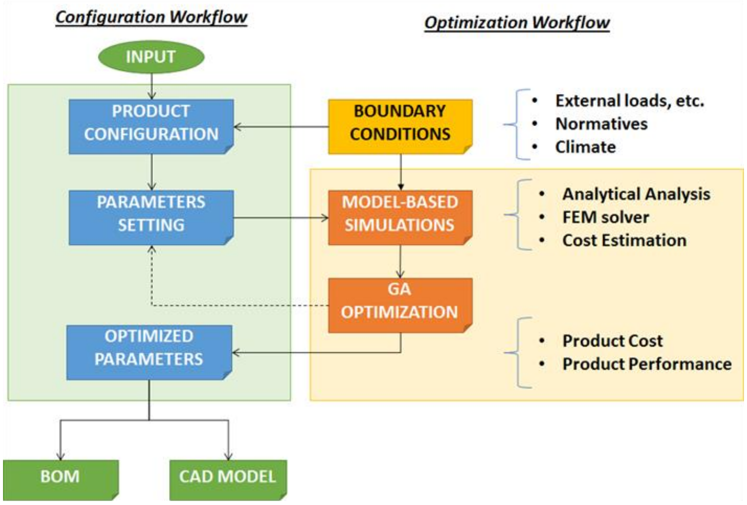

Fig. 1: The proposed methodological approach.

A gas turbine chimney, which is the object of the proposed test case, is a vertical insulated steel duct with a circular section (Fig. 2a). The internal diameter is constant and its value depends on the size of the gas turbine involved in the power plant to engineer. A chimney, used in gas turbines, consists of several flanged cylindrical ducts. The thickness of the ducts decreases from the base duct to the last item, and this issue was considered in the optimization analysis. The parameters to optimize, during the early design phase of an oil & gas chimney, are the thickness and the height of each duct item. Since the total height of a chimney is fixed, the definition of the height of each duct is an indirect way to define the number of duct items involved.

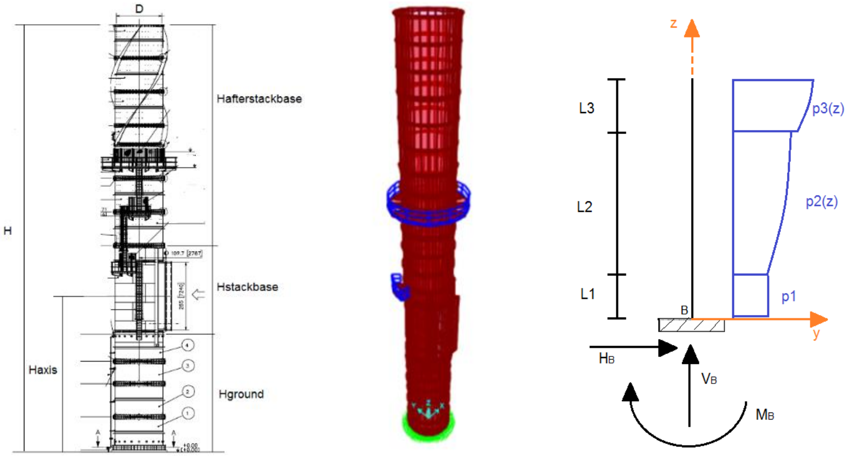

Fig. 2: a) An example of an oil & gas chimney for gas turbine plants; b) a shell model of a chimney; 2) a schematic representation of load applied.

An already developed software has been used to configure and generate the 3-D model of the exhaust duct, used as a test case. The configuration framework was implemented using the Siemens Rulestream development platform. The input of the chimney configuration is the data about the gas turbine involved, the climate data with the geographic locations, the reference standards and normative, the maximum height of the chimney and the height of the stack base.

The configuration process regards the filling out of a configuration sheet, which collects all information for the CAD modelling and the early BOM generation. The configuration tool already implements knowledge for the correct selection of components and materials. The traditional output of the configuration is the definition of a chimney system, using already engineered duct items. The scope of the proposed test case is to test the use of tools and methods to optimize the output of the configuration with a MOO approach. Therefore, in this research, a plug-in has been developed to integrate the configuration workflow within an optimization analysis, which is based on a Model-Based simulation.

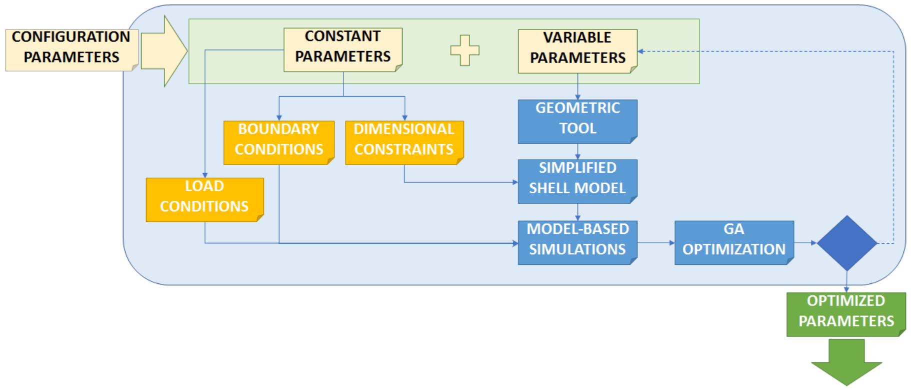

Fig. 3: The workflow of the plug-in developed to support the optimization during the configuration.

The developed plug-in reads all parameters from the previously defined configuration sheet and sets the variable of the optimization workflow. The optimization tool has been developed using the platform provided by the MODEfrontier tool, which implements genetic algorithms (GA) to solve maximum and minimum problems. The performed optimization workflow imports all constant and variable parameters related to the chimney project to configure and optimize. A geometric tool is responsible for the generation of a simplified geometry to be imported in the Model-Based simulation. This geometry

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is a shell object (Fig. 2b), which consists of different cylinder surfaces (Fig. 4). The thickness and material of each surface are properties set in the Model-Based definition.

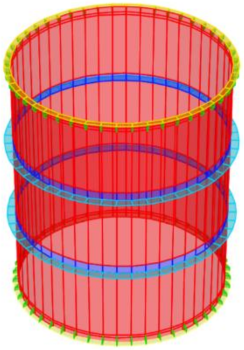

Fig. 4: A simplified shell model of a duct item.

A Model-Based simulation approach represents a physical system by object-oriented (O-O) blocks, where each block contains information and functions regarding the estimation of performance and system behavior. The model-based approach is an engineering design method applied in several fields such as mechanics, informatics, and electronics.

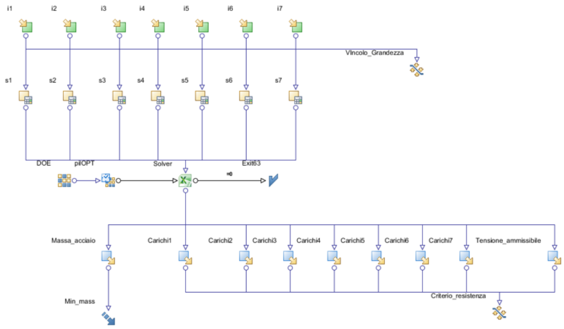

Fig. 5: The optimization workflow.

This paper considers within the Model-Based simulation a multi-level analysis, which regards a first analytical study of the loading conditions, the FEM (Finite Element Method) simulation of the mechanical structure and the cost estimation. The analytical analysis of the loading condition is the first analytical 0-D study which gives feedback about the average stress applied to a simplified chimney structure (Fig. 2c). This phase is above the complex 3-D FEM study, which regards the simulation of the mechanical-structural performance applied to the shell model of the chimney. This FEM simulation has been performed with the use of the SAP2000 solver. Using the API tools, provided by SAP2000, an algorithm has been implemented in VB-script language to update the Model-Based simulation with parameters and geometry related to the chimney configuration to be optimized. In particular, the values of thicknesses and heights are the variable parameters driven by a GA optimization loop (Fig. 4). The final level of analysis regards the analytical estimation of the manufacturing cost related to the configuration analyzed. The advantage of a Model-Based simulation approach is the definition of a previous parametric model, which is easy to reconfigure for the analysis of further product configurations. The updating of the Model-Based simulation also regards the definition of boundary conditions and load combinations to analyze, which are related to the constant parameters such as the environmental conditions and normative previously defined in specifications. Concerning standards and normatives to be used, the proposed test case considers ASCE/SEI 7-05 for the definition of the loads conditions and ANSI/AISC 360-10 for the stress checking. The analyzed optimization functions are the cost reduction and the weight minimization. The constraints of the optimization focus on the stress check related to the FEM analysis. At every calculation loop, the optimization workflow changes the values of each parameters

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using a GA approach. Each FEM simulation takes about 1 minute for the calculation considering static and seismic analyses.

Conclusions:

An approach to support the design optimization during the configuration phase has been proposed for ETO products in order to reduce design time and cost for the order quote. A plug-in tool has been implemented to connect the configuration parameters with the workflow developed for the optimization with Model-Based simulation. The proposed method aims to overcame the limits of traditional commercial tools which are not performed to integrate product configuration with design optimization. A test case was performed on the configuration of an optimized gas turbine chimney. The use of the proposed tools and methods has brought a great benefit in terms of reduced design time and weight in the context of chimney design.

Acknowledgements:

This research has been developed thanks to the collaboration and funding of General Electric Oil & Gas SpA and Hyperlean Srl.

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