STRUCTURAL OPTIMIZATION USING BIOLOGICAL GROWTH METHOD IN ANSYS MECHANICAL, PART I

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Abstract: *This article focuses on a lesser-known alternative of structural shape optimization, based on morphing the mesh elements using the Biological Growth Method (BGM) and its implementation using the Ansys Mechanical program and newly developed software – M3Opti. The aim of these activities is to improve the properties of a structurally complex parts or assemblies, which requires an advanced materials models and contact or geometrical nonlinearities. The part I of the two-part paper presents the theoretical background and describes implementation in Ansys Mechanical.*

Keywords: Structural optimization, shape optimization, Ansys Mechanical, Biological Growth Method, FE mesh morphing.

1. Introduction

Nowadays a variety of optimization algorithms based on different principles are currently employed for structural optimization. Probably the most well-known is Topology Optimization (TO), which adjusts material distribution in given design space. However, TO is just a one group from wider structural optimization family. The second group is sizing optimization, and the third one is Shape Optimization (Bendsoe, 2004). Sizing optimization is based on modifying existing parametrized geometry via change of parameters. On the other hand, Shape Optimization is based on morphing existing geometry which does not have to be parametrized. From this point of view Shape Optimization is suitable for complex geometries which cannot be easily parametrized.

As for topology and sizing optimization, also for shape optimization there are several different specific algorithms. Proposed algorithms can be divided based on their principle into three categories (Hsu, 1994):

- Sequential Programming,
- Direct Search,
- Biological Growth.

Every proposed algorithm needs to determine structural performance of optimized problem to perform optimization steps. This is mainly achieved utilizing FEM and this step is common for all categories. Optimization procedures differ for different optimization algorithms, but they are regularly utilizing FEA to gain structural response.

Among all methods Biological growth Method (BGM) (Arutyunyan, 1988; Azegami, 1990; Mattheck, 1990; Mattheck, 1990; Porziani, 2020) has strong advantage because it does not require any mathematical programming techniques as Sequential Programming or Direct Search which often requires gradient calculation (Hsu, 1994). The term "Biological Growth Method" is quite broad and could refer to various processes or techniques used in biology for the growth, cultivation, or manipulation of biological organisms. In the context of structural optimization, biological principles can be applied to reduce stress

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or other adverse properties in the surfaces of a structure, like the way bones or plants grow. In the more stressed regions of structures material swells simulating the growth mechanism of living organisms.

The reminder of part I presents implementation of Shape optimization utilizing BGM method in stand-alone software utilizing Ansys Mechanical. The principles and methods used in algorithm are described in Chapt. 2. Implementation is discussed in Chapt. 3. Application of this method is demonstrated and discussed in part II (Čada, 2024).

2. Methods

2.1. Mesh morphing

The principle of applying shape optimization with FEA isn't overly complicated. The main idea is based on mesh morphing as a mechanism for geometry change (Fig. 1), which is the simplest and fastest way to alter the shape of structurally complex parts.

It's necessary to determine the amount of shape change depending on the observed parameter (e.g. stress) which serves as objective function. Then, the change in shape of the structure can be achieved using mesh morphing. However, this method comes with limitations regarding the extent of shape change while preserving mesh topology. Each new mesh must meet quality criteria for elements and the adequacy of element density in a given area. If the criteria for mesh suitability are exceeded, remeshing (changing mesh topology) to a more suitable one is necessary. The direction of adding/removing material (movement direction of mesh nodes) is most suitable perpendicular to the surface of the structure.
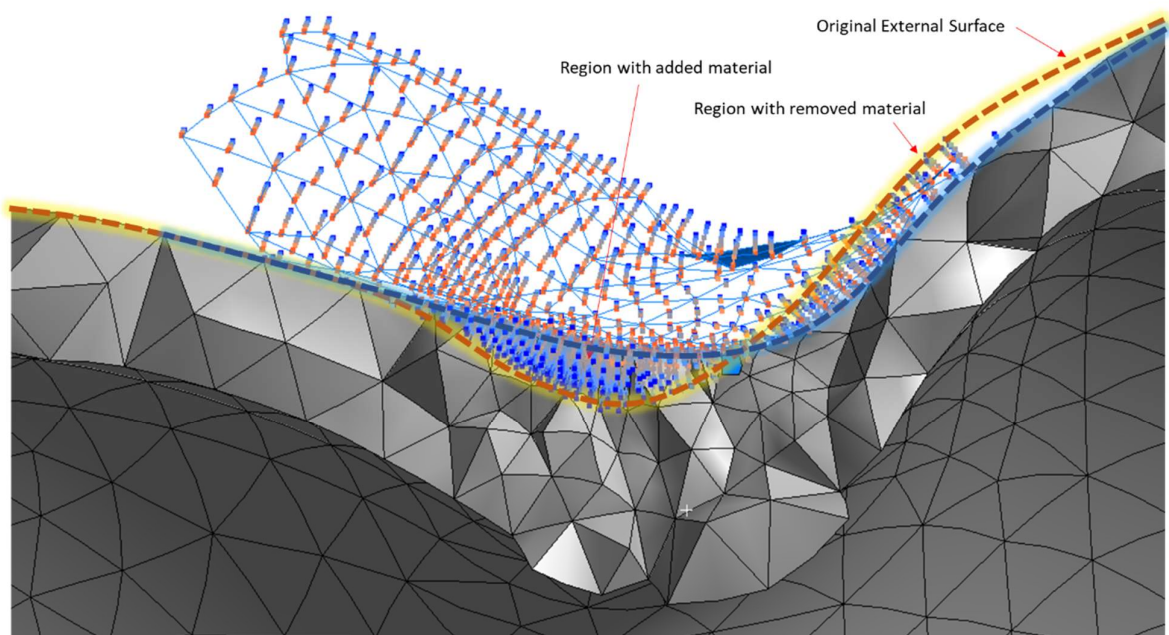

Fig. 1: Morphing example.

2.2. Application to structures

From the perspective of application to constructions, it's essential for the engineer to define areas of interest which will be modified. It's not always appropriate or possible to modify all regions of the structure together (Fig. 2). Furthermore, the engineer must define an objective function, meaning the result quantity such as von Mises stress, plastic strain, number of fatigue cycles, etc. and whether it needs to be minimized or maximized, as well as whether the dependency is linear, exponential, logarithmic, etc.

The threshold for determining whether material will be added or removed is often challenging to determine. From performed tests it has been found that the most suitable choose is based on a quantile of current values in the region of interest. Default threshold is calculated for each new design as 50 % quantile of nodal results which gives ratio how much material is added or removed, and this corresponds to moving distance of nodes (Fig. 3).
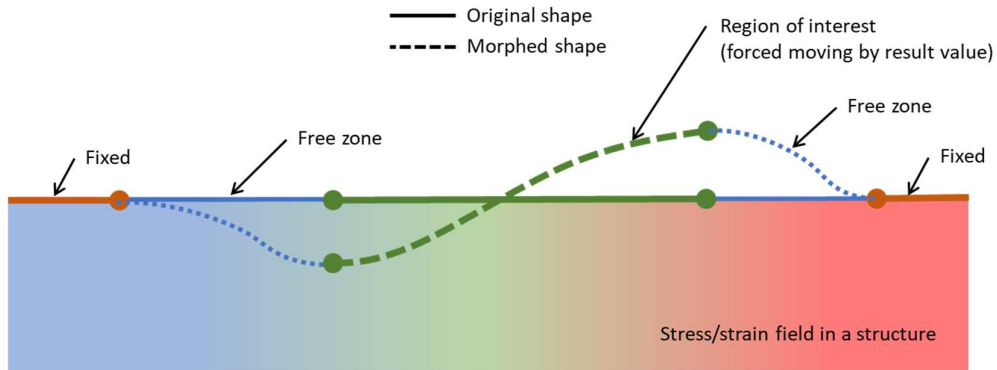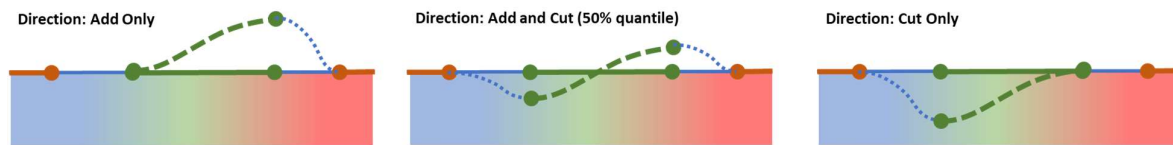
Fig. 2: Region of interest, morphing.

Fig. 3: Material adding or cutting.

The chosen result (quantity) as the source of values for calculating the objective function in the region of interest may not always be a continuous and smooth function, which can lead to undesirable shapes of the structure (Fig. 4). Therefore, it was deemed appropriate to perform additional smoothing. This approach to morphing has proven to be significantly more stable.
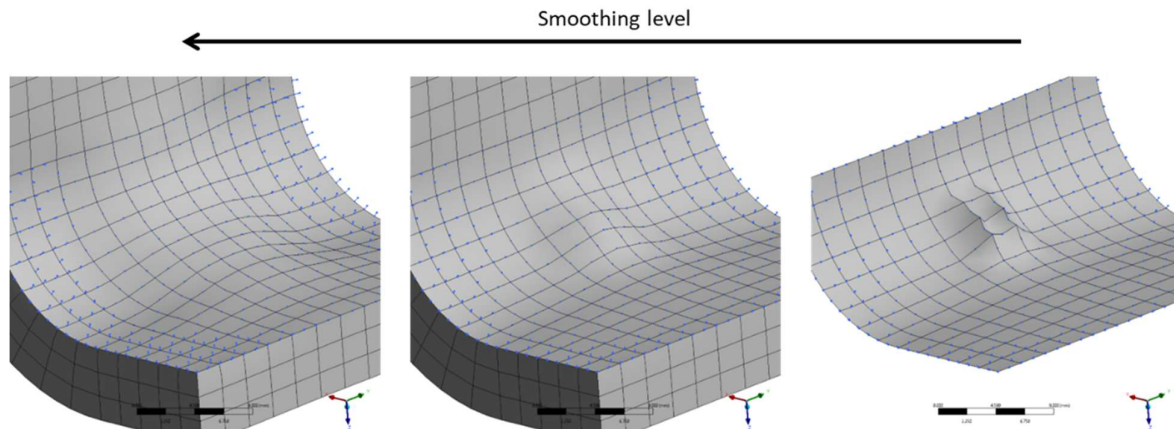

Fig. 4: Smoothing during morphing.

2.3. Iteration process, growth step size

In order to increase the stability of optimization calculations, various sizes of morphing steps (maximum node displacement) and the number of iterations were tested. The dependence on mesh size, morphing step, and the progression of improvement in the monitored variable within the chosen region were tracked. It was found that choosing a step size roughly ten percent of the size of adjacent elements typically resulted in decent stability in calculations, and the number of iterations to reach the optimum could be in the order of units (see Chapt. 3).

3. Ansys Mechanical implementation (M3Opti)

Software Ansys provides a several possibilities how to automate or customize calculation processes. The basic idea of customization is based on providing API of Ansys Mechanical (Ansys Help Documentation) which provides its object structure a can be used for controlling software programmatically.

Approach with standalone application has been chosen for implementing BGM algorithm for shape optimization. Main advantages of using stand-alone application over direct integration inside Ansys Mechanical are:

- application is alive while Mechanical is busy (not-responding),
- application can run on another computer than solver (Mechanical),
- postprocessing of optimization can be done without Mechanical.

Created application, which we named M3Opti (Mechanical Mesh Morph Optimization) controls Ansys Mechanical and uses its functionality for structural simulations and mesh morphing. It is a simple environment with GUI that allows users to set up a few necessary inputs and to display tables and charts during optimization. To achieve this, we have opted our own approach of port communication between Ansys Mechanical and M3Opti (ACT – Ansys Customization Toolkit).

Another approach which is possible for creating such an application is to use the newest technology for scripting and customization – PyAnsys (PyAnsys). This technology could be very useful for this purpose because it has embedded server-client communication and allows to communicate with Mechanical API directly from a standalone Python whit much less effort and programming experience required than in proposed solution.

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