

Visualization of energy efficiency of using a material in a deformable solid

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Abstract

Among scientific visualization systems, CAE (Computer Aided Engineering) post-processing tools hold a special place, the feature of which is their integration with CAD (Computer Aided Design) systems, which are essential in the daily activities of a design engineer. At the same time, the task of expanding and deepening the standard functionality of CAE postprocessors as a research tool that allows performing analysis of the design solution against various criteria is relevant.

This paper presents the SolidWorks (Simulation) add-in, which visualizes the state and behavior of a deformable solid in terms of the energy efficiency of using the material. The criteria for the efficiency of using the material are considered.

A solution in MS VisualStudio C ++/C # environment for SolidWorks Simulation based on API (Application Program Interface) SolidWorks and COM (Component Object Model) is presented, which expands and complements the standard SolidWorks functionality in terms of visualization of the specified criteria and parameters of the stress-strain state of a deformable solid.

Keywords: CAE systems postprocessors, energy criterion of material use efficiency, SolidWorks Simulation, stress-strain state.

1. Introduction

For both the developer and the user, CAE postprocessing tools are characterized by properties similar to those of modern all-purpose scientific visualization systems. In this context, several levels and directions of development of CAE post-processing tools should be noted.

1. Cyber-physical multiplatform systems based on IoT technologies that provide tools for high-level adaptation to the data source from the solver (processor) [1,2];
2. Web services that provide post-processing for the finite element method. It is assumed that the user uses his own finite element processor, and the post processor uses user data and is implemented in an OpenGL-based cloud [3].
3. Expansion of the post-processor functions based on augmented and virtual reality technologies [4,5,6].
4. Development of applications for CAE, designed to solve specific visualization problems in the environment of a particular CAE system [7-9].

This paper considers the solution of a particular visualization problem for CAD/CAE SolidWorks (Simulation).

The most relevant to this article is work [9], which solves the problem of analysis and visualization of three-dimensional objects' illumination. The problem is solved by an add-in application for SolidWorks (Simulation). This approach, both in [9] and in this work, has an obvious advantage: standard CAD/CAE modeling functions are used, including discretization algo-

rithms and other functions of finite element processing, database management tools, export-import procedures, and user interface.

Due to the fact that to date, there is still no unified theory of strength, theories and approaches based on own criteria are being developed again. In engineering practice, the problem of multiple choice of strength criteria, qualitative comparison of the analysis results, including the visual analysis, is relevant.

In particular, V.P. Malkov proposed an energy criterion for the efficiency of material use [10, 11], which can be used for both a qualitative and quantitative assessment of the effectiveness of a design solution in terms of strength. A visual presentation of the project in these terms that correspond to different strength criteria, can be used both in solving optimization problems in a strict formulation, and in trial design.

To determine the energy criterion for the efficiency of material use, a number of well-known relationships in the mechanics of a deformable solid are used [10, 12, 13]. In particular, the specific potential energy of elastic deformation of an isotropic deformable solid is determined as

$$U_0 = \frac{1}{2} (\sigma_x \varepsilon_x + \sigma_y \varepsilon_y + \sigma_z \varepsilon_z + \tau_{xy} \gamma_{xy} + \tau_{xz} \gamma_{xz} + \tau_{yz} \gamma_{yz}) = \frac{1}{2} (\sigma_1 \varepsilon_1 + \sigma_2 \varepsilon_2 + \sigma_3 \varepsilon_3) = \\ = \frac{1}{2E} [\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\mu(\sigma_1 \sigma_2 + \sigma_1 \sigma_3 + \sigma_2 \sigma_3)],$$

where $\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz}$ и $\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{xz}, \gamma_{yz}$ – are the components of the stress and strain tensors, respectively; $\sigma_1, \sigma_2, \sigma_3$ – are the principal stresses, $\varepsilon_1, \varepsilon_2, \varepsilon_3$ – are the principal strains, E – is Young's modulus, μ – is Poisson's ratio.

On the basis of the available experimental diagrams under tension, compression, and pure shear, one can judge the limiting states of the material in the vicinity of dangerous points at which the maximum values of one or another numerical criterion are observed. Then the permissible (limiting, i.e., with a safety factor equal to one) specific energy densities can be respectively determined for the cases of tension, compression and shear as follows:

$$[U_0]_+ = \int_0^{\sigma_L^+} \varepsilon(\sigma) d\sigma, [U_0]_- = \int_0^{\sigma_L^-} \varepsilon(\sigma) d\sigma, [U_0]_0 = \int_0^{\tau_L^0} \gamma(\tau) d\tau.$$

In these formulas $\sigma_L^+, \sigma_L^-, \tau_L^0$ – are the stress values for tension, compression and shear, respectively, that are limiting values for the material.

For materials operating in the linear-elastic stage, these formulas take the form:

$$[U_0]_+ = \frac{(\sigma_L^+)^2}{2E}, [U_0]_- = \frac{(\sigma_L^-)^2}{2E}, [U_0]_0 = \frac{(\tau_L^0)^2}{2G}.$$

In turn, the type of stress state can be characterized using the Lode-Nadai parameter [10, 12]:

$$\chi = 2 \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} - 1, -1 < \chi < +1,$$

Thus, at $\chi = -1$ – we have tension, at $\chi = +1$, compression,

at $\chi = 0$, shear. For mixed stress states, the permissible specific energy density can be determined by the formula [10]:

$$[U_0] = \min([U_0]_+, [U_0]_-, [U_0]_0).$$

Then the local (specific) energy criterion [10] can be defined as

$$\eta_0 = \frac{U_0}{[U_0]}.$$

To determine the global energy criterion η [10], body volume integration should be performed:

$$\eta = \frac{\int_{V_0} \eta_0 dV}{V_0} = \frac{\sum_{i=1}^{N_{FE}} \eta_0^{(i)} V_i}{V_0},$$

where V_0 is the body volume. Given here is also a formula for determining η in case of finite element discretization, V_i is the volume of the i -th finite element, N_{FE} – is the number of finite elements.

Thus, for the qualitative and quantitative assessment of the design solution, visualization distribution of the parameters U_0, χ, η_0 across the volume of the body being deformed, as well as the value of the integral parameter η are of interest.

2. Software Implementation

In SolidWorks terminology, among many terms – add-in, application, plugin – in the Russian version, preference is given to the term “Add-in”. Add-in module is created as a DLL library and is a COM server, i.e. SolidWorks in this case is an application that initiates the execution of the functions of our Add-in module (SwAddin). The module is registered in the system by the RegAsm.exe utility.

At startup, SolidWorks checks the registry for add-ins (SolidWorks applications), creates an add-in-associated object, and searches for a SwAddin object. The Add-In module calls the ISwAddin::ConnectToSW function to connect to SolidWorks.

When disconnecting, SolidWorks calls ISwAddin::DisconnectFromSW, allowing the application to clean up.

In addition, the function ISwAddin::ConnectToSW returns the pointer to the top-level application object of ISldWorks.

In practice, the main functionality of the add-in, as a rule, is implemented by a separate DLL module, separated as much as possible from the interfaces and loaded by the Add-in. Figure 1 shows the solution for the problem under consideration in the MS VisualStudio C++/C# environment.

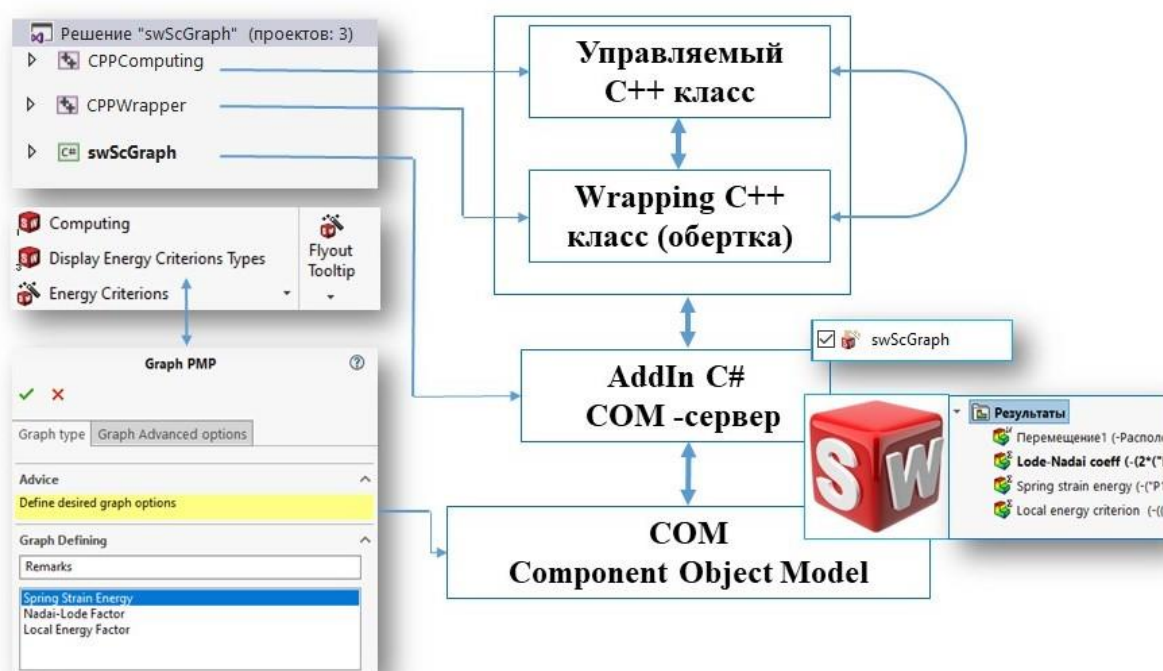


Fig. 1. Solution in the MS VisualStudio C++/C# environment

The chosen solution structure is due to a rather typical situation, which is associated with the need for a modular representation of the solution in different programming languages. In this case, the solution comprises three projects.

1. The first project is designed to implement computational procedures and includes a special C++ class CPPComputing. This is due to the fact that a large amount of software has already been created using C++ (including by the authors), which can be included in this solution or during its further development.
2. The C# swScGraph project, implementing SolidWorks COM server and the corresponding interface.
3. Wrapping – CPPWrapper class (wrapper) provides swScGraph with access to the methods of the CPPComputing class.

At the same time, SolidWorks API provides access to the parameters of the finite element mesh and to the solution results necessary for the numerical implementation of the above formulas.

3. Results

The method presented in the article is illustrated by the example of an equally stressed beam with two types of cross-section: rectangular section (figure 2 A₁) and near-I-section (figure 2 A₂).

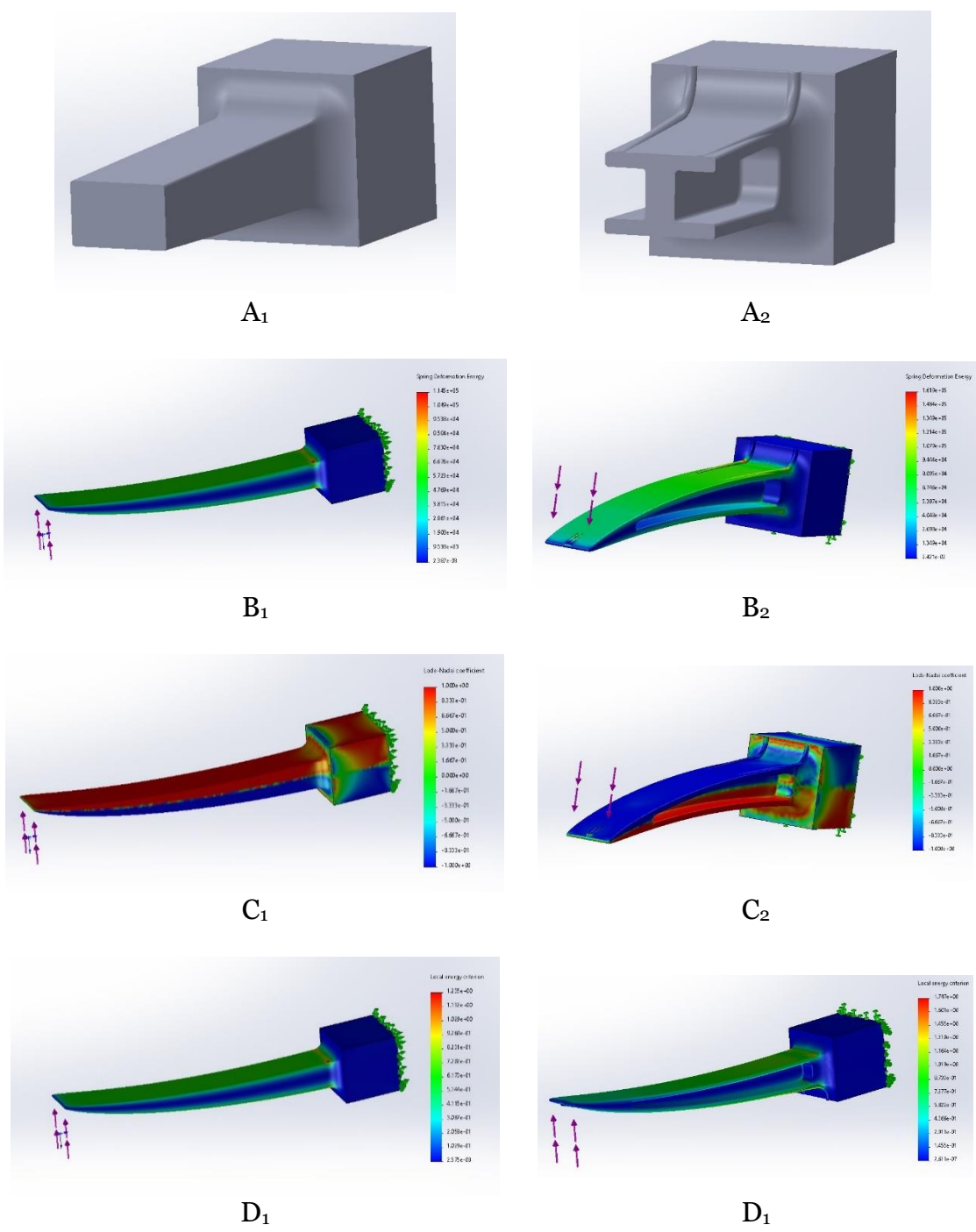


Fig. 2. Results of the problem solution for an equally stressed beam. A– cross-section. B – specific elastic potential energy. C – Lode-Nadai parameter. D – local energy criterion. Index 1 corresponds to a beam with a rectangular section, index 2 corresponds to an I-section beam.

In addition, the I-beam is reinforced with longitudinal stiffeners, which, along with fillets, are introduced into the solid model in order to reduce stress concentration, possible singularity and edge effects [12, 13]. Further, Figure 2 B₁-2 D₁ и 2 B₂-2D₂ shows scalar fields in the form of maps (diagrams). Figure 2 B₁- 2 B₂ is the result of the work of the standard SolidWorks Simulation functionality, and Figures 2 C₁-D₁ и 2 C₂-D₂ were generated by an application developed by the authors. It should be noted that in the latter case, all the standard functionality of SolidWorks Simulation is preserved in terms of visualization of the resulting scalar fields: scaling, probing, assigning a scale (legend), a color palette, etc.

From Figures 2 C₁ - 2 C₂ it can be seen that for a reinforced I-beam the Lode-Nadai parameter has higher gradients compared to a rectangular one, which indicates a more complex combination of types of stress state in the volume of the body. For the specific potential energy of elastic deformation and the local energy criterion, an opposite situation is observed, i.e., the gradients of these fields are lower (Figure 2 B₁ - 2 B₂ и 2 D₁ - 2 D₂ respectively). In this case, the global energy criterion for the I-beam increased to $\eta = 0.62$ from $\eta = 0.32$, determined for the rectangular section.

It is important to note that for graphic objects generated by the application, all the standard SolidWorks Simulation rendering functionality is preserved even if they are animated. Thus, Figure 3 shows the change of the local energy criterion in the form of animation when the external load parameter increases from zero to a finite value (Figure 3). In this case, as in all similar cases of static loading, the scale factor for deformations is set by the user for reasons of clarity of the resulting deformed state.

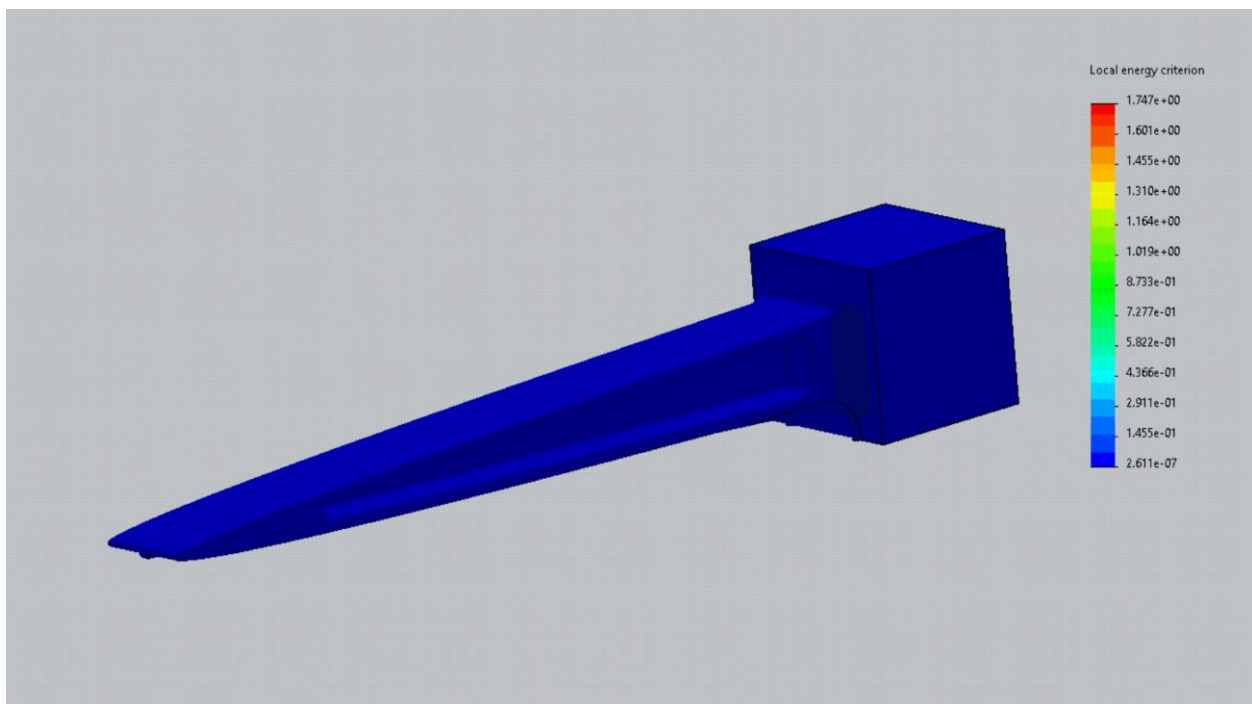


Fig. 3. Animated change in the local energy criterion.

4. Conclusion

The article presents software that expands the standard functionality of SolidWorks Simulation in terms of visualization of scalar fields of the stress-strain state under static loading. The problems of full-strength (equally stressed) design known in engineering practice were considered as test problems.

The application is ready for practical use and has no restrictions for qualitative and quantitative assessment of the efficiency of material use in real load-bearing structures based on the criterion under consideration.

Prospects for the work should include the extension of the application's functionality to problems of dynamics, e.g., to analyze the impact of solids. In this case, the software requires refinement and, in the context under consideration, is reduced to visualization (animation) at a finite time interval of not only scalar, but also vector fields associated with energy flows and the processes of its transition from one type to another.

The authors are prepared to provide the software developed by them in source code to all those who wish to use it for solving their research problems.

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