INTELLIGENT SUPPORT TO ANALYSIS-BASED DESIGN IMPROVEMENT PROCESS

PROPOSE: An Intelligent Consultative Advisory System

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Abstract: The paper presents the use of intelligent consultative decision support computer system in engineering design. The system presented is able to provide an expert advice to designer engineers how to improve a certain design solution considering the results of the preceding engineering structural analysis. The system guides design engineers through the post-processing phase of the structural analysis and suggests them the appropriate redesign actions in case the structure is under- or over-dimensioned. The application of the system in practice is presented by two examples.

1 INTRODUCTION

Engineering design is a set of decision-making processes and activities used to determine the form of an object. Considering the technical, economic, safety, social and certain other constraints, the designers use their creative abilities to synthesize alternative design solutions.

Engineering analysis can prove or reject a design candidate by predicting and simulating its performance or behaviour. Structural analysis is thus an integrate part of the design process for many components. Finite Element Analysis (FEA) is the most extensively used numerical analysis in mechanical engineering practice and is incorporated into many computer aided design systems (Zienkiewicz, Taylor and Shu, 2005). A candidate design that fails to satisfy the constraints should be modified, new values regarding form should be chosen, and the changed/redesigned candidate reanalyzed. Engineering analyses play a very important role in the design improvement process.

The skilled usage of Computer Aided Design (CAD) tools increases the designers' effectiveness and their capabilities when solving complex design problems (McMahon and Browne, 1999). CAD systems cover different design activities, such as modelling, kinematics, simulations, structural analysis or just drawing technical documentation. In spite of all this, these kinds of systems do not offer sufficient support to the designer during the more creative parts of the design process involving complex reasoning as, for example, when a possible candidate design needs to be evaluated and modified.

In analysis-based design improvement process the results of engineering analysis need to be studied and decisions made regarding the design's suitability with respect to its engineering specifications. In general, design changes are indispensable and designers need help to deal with this problem properly.

The prototype of an intelligent rule-based consultative system is being developed by the authors to provide such advice when considering a description of the design structure's critical area. The system can deal with the results of prior strain-stress or thermal analysis. It presents a short list of proposed design changes that should be taken into account when improving the design.

According to the experience gained so far by applying the system in engineering practice as well as in design education, redesign recommendations presented as a list of the proposed design changes can support decision making process significantly.

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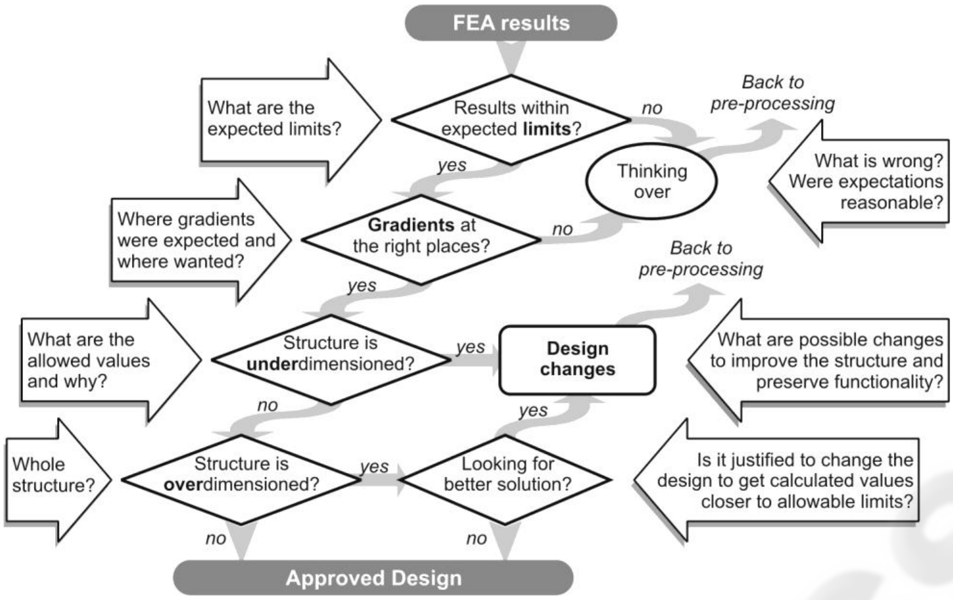

Figure 1: Some crucial decisions in FEA-based design improvement process.

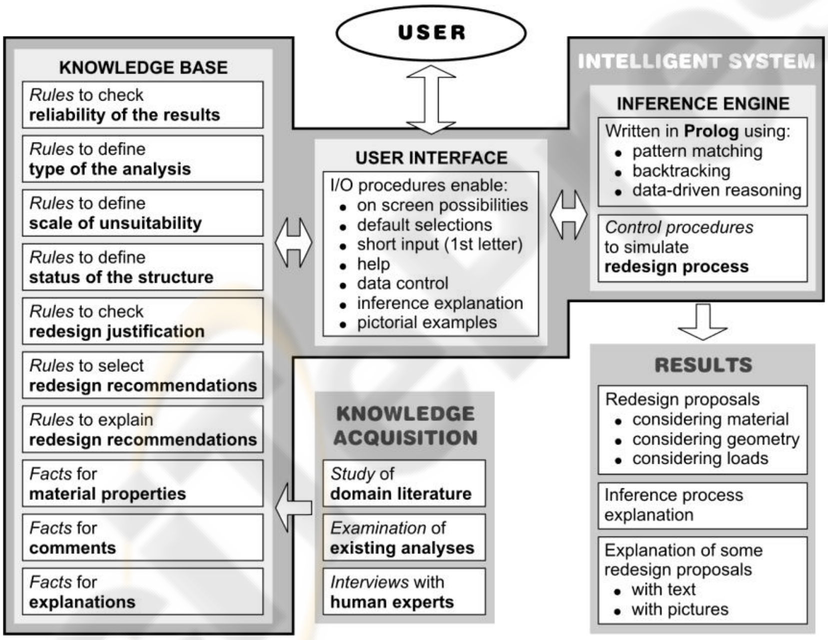

Figure 2: Basic architecture of the PROPOSE system.

2 ANALYSIS-BASED DESIGN IMPROVEMENT

Design is iterative process. How many iteration steps are needed directly depends on the quality of the initial design and later design changes. Basic parameters for design improvement process are often the results of some engineering analyses. Post-processing phase of the engineering analysis represents a synthesis of the whole analysis and is therefore of special importance. It concludes with the final report of the analysis, where the results are quantified and evaluated with respect to the next design steps that have to follow the analysis in order to find approved design solution. At this point, FEA software offers an adequate computer graphics support in terms of reasonably clear pictures showing a distribution of unknown parameters inside the body of the structure. However, the user still has to answer many questions and solve many dilemmas in order to conclude the analysis and to choose the appropriate redesign steps. Figure 1 shows basic algorithm that the design engineer have to perform in analysis-based design improvement process.

It is obvious the algorithm presented requires a lot of knowledge and experience, not only in the area of analysis itself, but also in design, giving the word design its broadest meaning. Designer has to be able to judge, whether the results of the analysis are correct and reliable, and also to decide what kind of design changes are needed, if any.

Many young inexperienced engineers need intelligent advice to perform the analysis' results interpretation and consequent design improvement process adequately. Unfortunately, this kind of help still cannot be expected from the present FEA software, as the traditional systems are rather concentrated on numerical aspects of the analysis and are not successful in integrating the numerical parts with human expertise. Intelligent decision support is required (Turban, Aronson and Liang, 2004).

3 PROPOSE – INTELLIGENT DECISION SUPPORT SYSTEM

A prototype of the intelligent system named PROPOSE, is being developed to support analysis-based design improvement process (Novak and Dolšak, 2008). PROPOSE provides a list of redesign recommendations that should be considered to improve the design candidate considering the results of a prior analysis. As a rule, there are several redesign steps possible for design improvement. The selection of one or more redesign steps that should be performed in a certain case depends on the requirements, possibilities and also on wishes.

The most important part of the system is the knowledge base. The theoretical and practical knowledge about design and redesign actions are presented within the system in form of production rules.

As it can be seen in Figure 2, the knowledge base of the system is consisted of many different types of rules and facts that are necessary for the system to be functional. For example, several rules are needed just to define the status of the structure (not stiff enough, under-dimensioned, over-dimensioned or satisfactory). However, from the technical point of view, the most important rules in the knowledge base are those defining redesign recommendations.

The system is encoded in Prolog that was chosen because of its built-in features such as rule-based programming, pattern matching and backtracking (Bratko, 2000). Our work was concentrated on declarative presentation of the knowledge, using data–driven reasoning, which is built in Prolog. However, some control procedures were also added to the inference engine of the system to adjust the performance to the real-life design process.

For the user interface, our goal was to simulate the communication between the student and design expert. As presented in Figure 2, the user interface has many features including help, which enables the efficient and user-friendly communication. It is however evident that PROPOSE is a prototype, which is still the subject of research and, as such, cannot be compared with commercial software.

A detailed description of the system architecture including all development phases can be found in (Novak and Dolšak, 2008). Here we will concentrate on some application characteristics of the system.

4 APPLICATION OF THE PROPOSE SYSTEM

In order to use the system, the user simply needs to run the executable file "PROPOSE.exe". The execution starts with the system introduction presented on the screen including some basic information how to use the system. From that point, the system leads the user from the specification of the problem to the final conclusions and recommendations for design improvement. The actual data flow that is followed in the application process is presented in Figure 3.

First, the user needs to present the qualitative manner of the information about the results of the engineering analysis: the results reliability, the type of the engineering analysis (strain-stress or thermal analysis), the results deviations from allowable limits, the type of the structure and the abstract description of the problem area. In case the problem area can be described in different ways, it is advisable to do so, as the system will be able to propose more improvements that are possible.

Help is available through the whole data input process. For every problem area, the system searches for the redesign recommendations in the knowledge base. The results in form of the redesign recommendations are written on the screen. The user can also get insight into the inference process.

If required by the user, the system presents all the steps that led to the final conclusion together with the list of recommended design changes.

In addition to the explanation of the inference process, the user can also get more information about certain redesign proposals. This kind of information is provided not only for the geometry changes, but also to support the selection of more relevant material. Redesign proposals are explained with text or with pictorial examples. Some proposals are explained in either ways.

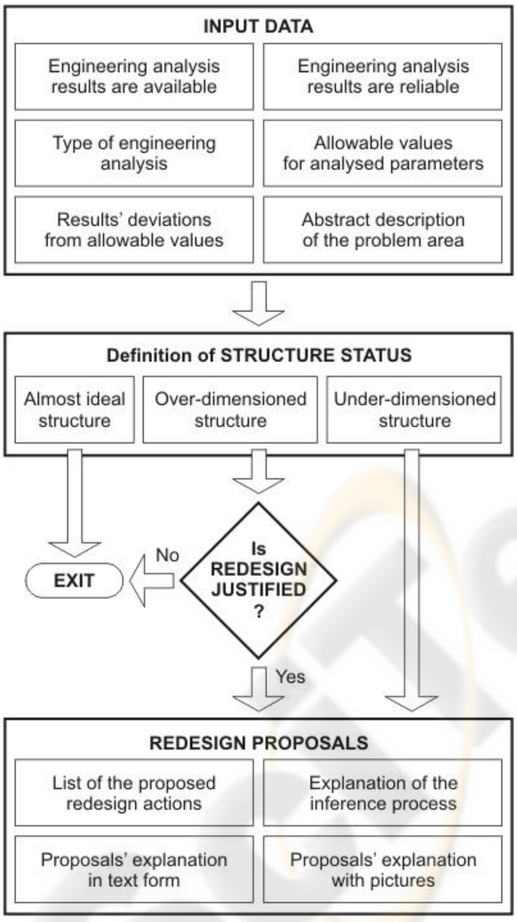

Figure 3: Data flow of the PROPOSE system.

5 PRACTICAL EXAMPLES

In continuation, two design studies are briefly presented to demonstrate the use of PROPOSE system in practice. Complex, expensive and time consuming analysis-based design improvement is justified and makes sense when the product needs to satisfy certain structural and other specific criteria.

Mass production where even small savings per single product can lead to significant savings for the whole production quantity is the other important optimization criteria. Our first example is an ice axe that has to fulfil very strict structural criteria, as the life of the user depends on its strength. At the same time the ice axe also needs to be as light as possible. Our second example is an open-end spanner. It belongs to the group of products that are produced in big series, while structural criteria are also prescribed in detail.

5.1 Ice Axe Design Optimization

Ice axe is special mountaineering equipment. Considering the strength, two types of ice tools exist. In the project presented here, the basic type with lower strength for use in general circumstances as on glacier for snow hiking, for ski mountaineering etc., was a subject of consideration. The material of the ice axe should be as light as possible, while at the same time it has to ensure the strength and toughness at low temperatures. There are several static, dynamic and fatigue test methods and requirements prescribed for the ice axe in special standards (EN-13089 and UIAA-152).

The optimization of the ice axe design was performed in step-by-step manner. First of all, a simple initial design was made in geometric modeller. This model and each consecutive design candidate was then analyzed according to the tests and requirements prescribed by the standard. After every analysis, the PROPOSE system was applied to get some recommendations for further design improvements (Kurnik and Zerdin, 2007). Figure 4 presents an example of the recommendations provided by the PROPOSE system.

In process of improving the ice axe design all three possible types of design changes (A, B and C) were made. The first FEA results for the axe “made” entirely from aluminium alloy clearly shown, that the pick of the axe is not strong enough. As a consequence, it was decided to design the axe as a combination of the steel pick and aluminium shaft (change type A). The position of the juncture between both parts of the axe was chosen carefully to move the force from the critical cross-section area (change type C). However, most of the changes addressed the geometric appearance of the axe (changes type B). In earlier design optimization phases, geometry was changed in order to improve

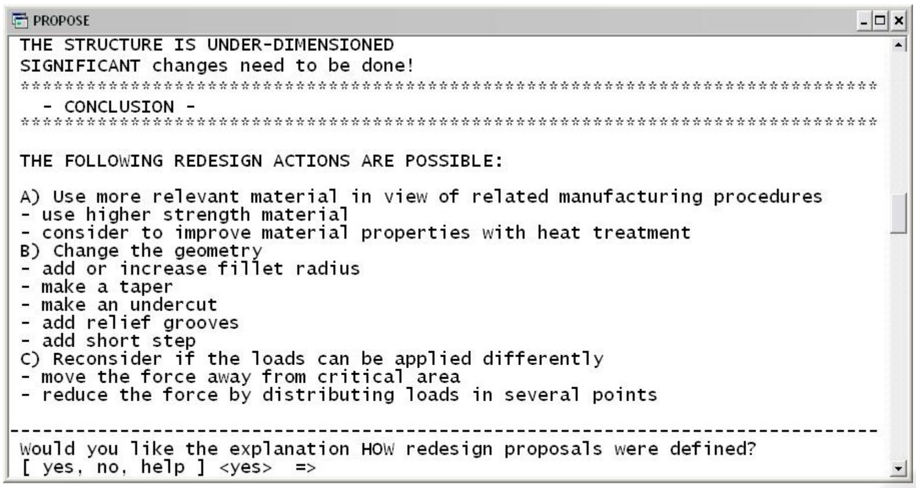

Figure 4: Screenshot of the PROPOSE application – design recommendations.

Figure 5: FEA results and design improvements for the ice axe pick (from left to right).

the strength and stiffness of the structure, while later geometric changes were applied to the ice axe design to make the structure lighter and at the same time to prevent the structural properties achieved earlier.

Following the optimization procedure introduced in this section, the final design of the ice axe pick was reached in three consecutive analysis-based design improvements, as shown in Figure 5.

5.2 Open-end Spanner Design Optimization

Open-end spanner is widely used hand tool that can be severely loaded and is forged in large quantities. Thus, analysis-based design optimization is more than justified. An extensive design study has been made by applying the PROPOSE system in one of the largest and most important Slovenian exporting company Unior, producing mainly forged parts, hand tools and machine tools (Podpecan, 2009).

The detailed results of the study contains some company's classified data. Here we would therefore just like to stress out the most interesting design change that was achieved following the recommendation of the PROPOSE system. In order to reduce high stresses in the opening corner of the spanner, one of the system's proposals was to add a relieving grove in that particular corner.

Figure 6 presents a pictorial explanation of this particular proposal presented by the PROPOSE system. At first sight, it seems quite odd to apply this proposal to the open-end spanner design. However, the execution of the proposed geometry change presented in Figure 7 resulted in noticeable decrease of the stresses.

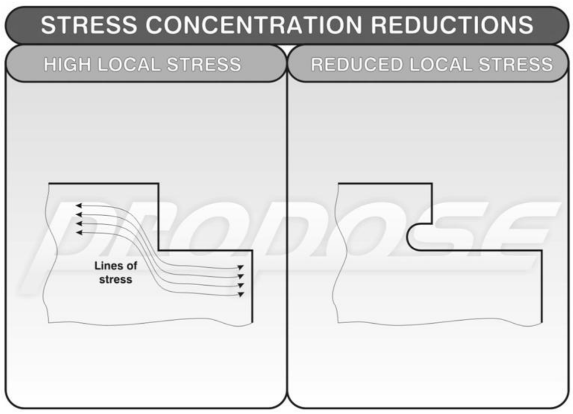

Figure 6: Explanation of the proposed design change.

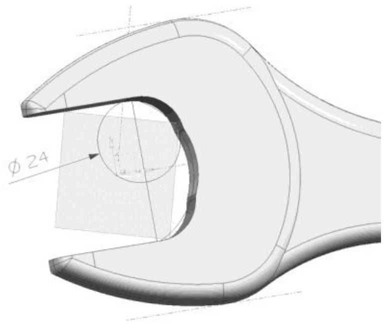

Figure 7: The execution of the proposed design change.

The functionality of the spanner remains unchanged, while material use and consequently the weight are reduced. Thus, analysis-based design optimization supported by intelligent advisory tool has proved to be successful again.

6 CONCLUSIONS

Structural analysis-based design optimization is a part of development process for many products. When numerical part of the engineering analysis is finished, designer has to be able to judge, whether the results of the analysis are correct and reliable, and decide what kind of design changes are needed, if any. Most of design engineers need "intelligent" advice to perform results interpretation adequately (Pinfold and Chapman, 2004). Unfortunately, this kind of help cannot be expected from the present software. For this reason, many research activities are oriented in making analysis-based design optimization process more intelligent and less experience-dependent (Chapman and Pinfold, 2001).

In this paper an intelligent aid for analysis results' interpretation is presented in form of the intelligent consultative advisory system, which provides a list of redesign recommendations that should be considered to optimize a certain critical area within the structure, considering the results of a prior stress/strain or thermal analysis.

The user has to define design problem and present the results of the engineering analysis. In addition, critical areas within the structure need to be qualitatively described to the system. These input data are then compared with the rules in the knowledge base and the most appropriate redesign changes are determined and recommended to the user. The abstract description of the problem area should be as common as possible to cover the majority of the problem areas, instead of addressing only very specific products.

In cases when the problem area can be described to the system in different ways, it is advisable to run the system several times, every time with different description. Thus, the system will be able to propose more design actions, at the expense of only a few more minutes at the console.

Some experts individually evaluated the system from two points of view. Firstly, they tested and evaluated the user interface of the system by inspecting how well the system helps and guides the user, or even enables him or her to acquire some new knowledge. Secondly, they analysed the performance of the system on some real-life examples. They evaluated the suitability, clearness and sufficiency of the recommended design changes. They all shared general opinion that the PROPOSE system is an effective tool, which provides useful guidance for further design steps. All comments, critiques and suggestions presented by the experts were taken into consideration and resulted into numerous corrections and adjustments of the system.

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