Design of Machines and Structures, Vol. 2, No. 1 (2012), pp. 63–72.
https://doi.org/10.32972/dms.2012.006

OPTIMIZATION POSSIBILITIES AND METHODS IN PRODUCT DEVELOPMENT AND QUALIFICATION

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Abstract
In this "state- of- the- art" paper the place and role of optimum design in product development process is described, based on the definition of products, definition of product quality and product qualification levels. Most important product characteristics and parameters are listed which can be subjected to optimization or multidisciplinary optimization (MDO) procedures. Case studies and numerical examples are shown for optimization, quality analysis, improvement and shape optimization of several industrial products and products designed by Industrial product and art designer students. The examples and case studies were selected from the industrial projects and students design and optimization works and results of the Department of Machine and Product Design at University of Miskolc, Hungary.

Keywords: product qualification, optimization methods, MDO, shape optimization of products

1. Introduction

In 1996 the Department of Machine Elements at University of Miskolc started the education of product development as a new formation course besides of machine elements and construction design. This resulted in the flare of the activity palette of the department. The education of product development invoked new disciplines as Product and Art Design, Integrated Product Design or Product Simulation. As a result of this new education activity, the name of the department changed the new name is: Department of Machine and Product Design since 2008.

During the design process of – not only industrial – products, besides the design of the shape, functionality and colours of the product, it is very important to keep the high standard of efficiency, reliability, economy (low material and manufacturing costs) or high load carrying capacity and longer life [1]. These characteristics could increase the added value content of the product or could give higher competitiveness. For the development and increase of these parameters of a product, it is unavoidable to apply and use the facilities and possibilities offered by multidisciplinary optimization (MDO) [2], the finite element method (FEM) [3], [4] and computer aided design (CAD).

In this paper the integration of these methods is presented into the product development process by showing several case studies and numerical optimization examples. Examples are shown for optimization, quality analysis, improvement and shape optimization of several industrial products and products designed by product engineering students.

The examples and case studies were selected from the industrial projects and student design and optimization works and results of the Department of Machine and Product Design at University of Miskolc, Hungary.

2. The place and role of MDO and FEM in the design and development of products

First of all, it would be necessary to repeat the well known definitions of product, product lifecycle, quality of product, product design, in order to place easier the FEM and MDO methods into this system. (The usage of a three dimensional CAD system is always necessary to create the models for FEM and MDO investigations.)

Product can be everything which is marketable, consumable, or usable, fulfilling a need, demand or request of the customers. As a simple approach, one can discuss three levels of the product:

a. Abstract product;
b. Manufactured product;
c. Complementary product.

The abstract level of product integrates all the advantages, provisions, services, supplies which can be associated to the image of the product and these will be the main reason to why buy the product (for example in case of food product the enjoyable taste, aroma, flavour, healthy effects, nutrition values, etc. or in case of furniture convenience, aesthetics etc.). At the level of abstract product, it is requested by the consumer that the product should work well and should carry the loads during the operation and usage. The verification of the product against these kinds of effects could be an entering point for FEM and MDO results into the product design process.

The product designer will transmit the abstract product into the manufactured product level. The manufactured product has its trade mark, name, form, characteristic colours, packing, technical parameters, quality, reliability, load carrying capacity, etc. The last four parameters already can be subjects of several finite element and optimization studies and improvement processes, the results of which can improve considerably some very important characteristics of the products. This is the most important point where the FEM and MDO methods could connect into the product design process.

The third level is the complementary product, which means some more or added services, characteristics of the manufactured product for example guarantee, assurance, set in operation, or in case of a software product the installation, upgrade, etc. If the manufactured product does not contain FEM or MDO results, this point could be also a possible place to call in these investigations into the product development process, for example by creating a new type of service as “optimized product” or “verified product”. Also it is possible to create some analysis, verification, optimization or improvement services for products after selling, similarly to the upgrade process, as “developed product”, “economic product” or “improved product”.

More detailed approach can be to define five levels of the product:

a. Elementary benefit;
b. Basic product;
c. Requested product;
d. Augmented product;
e. Potential product.

The “elementary benefit” level of the five level product definition could be associated to the abstract product” level of the three level product definition, therefore everything can be applied here what was mentioned for the abstract product level, concerning the possible entering way of FEM and MDO into the product design process.

The basic product incorporates all the advantages, characteristics, what where provisioned in case of the elementary benefit (for example yoghurt incorporates that it is healthy, enjoyable taste etc.).

The requested product contains all the requests, claims and demands of the customer concerning the product (for example easy to operate, practical, or in case of food good flavour etc.). This level could be associated to the "manufactured product" level of the three level product definitions, so this could be also an important entering point for the FEM and MDO methods into the product design process.

The "augmented product" collects more wishes of the customer above the "requested products" (for example more practical packing, more convenient delivery, better price/value ratio etc.) and the "potential product" contains all the characteristics and "dreams" which say how the product could be or will include future developments.

On the basis of the above mentioned things one can see that level d. and e. of the five level product definitions offer more possible ways for FEM and MDO investigation procedures to enter into the product design process.

2.1. Possible product characteristics which could be subjects of FEM and MDO investigations and qualification

The product lifecycle starts when the need for the product appears and ends with the end of the usage (when the product falls into oblivion). If the product development process results in newer and newer, better and better versions of the product, the "cycle" name is more and more appropriate, since the life process repeats cycle by cycle. In the lifecycle of every product one can find the design, experiment, analysis activity which helps the product development process from the beginning of the lifecycle until the starting of the manufacturing. This part of the lifecycle can be called as "product development". The most important possibilities for the application of FEM and MDO results are in this part of the lifecycle.

Let us overview the most important parameters or characteristics of products, which can be efficiently improved by the application of finite element and optimization results. The most important subjects of the machine- and product design could be the followings:

Drives:

- Gears, gear drives, gearboxes, conical gear drives, helical gears etc.
- Worm drives;
- Bevel gear drives;
- Belt drives, chain drives, friction drives;
- Harmonic drives, other special drives.

Bearings:

- Ball and rolling bearings, constructions containing bearings;
- Hydrodynamic, hydrostatic journal- and sliding bearings (axial, radial).

Shafts, couplings and their assembly elements:

- Behaviour of shaft- gear- bearing assemblies;
- Several couplings, having different operation concepts (mechanical, electrical, hydrodynamic etc).

Other important products and elements:

- Threaded connections;
- Seals;

- Brakes;
- Springs;
- Slider- crank mechanisms;
- Selected special elements for pipelines (pipe joints, valves, supporting structures for pipelines);
- Hand- tools and their elements;
- Household appliances, food processors;
- Tools to tinker and hobby;
- Cars and accessories or elements for cars;
- Furniture, artistic products;
- Children's toys and furniture;
- Office furniture and accessories;
- Computers and additional products;
- Medical tools, implants, accessories
- Etc.

Most important disciplines that could be involved and touched during the finite element analysis and multidisciplinary optimization of these elements are as follows:

Static:

- Linear static;
- Nonlinear materials;
- Large deformations.

Contact:

- Contact with or without friction;
- Lubricated contact;
- Wear and other forms of contact failure.

Dynamics:

- Eigenfrequencies, undamped and damped vibrations;
- Random vibrations, harmonic and random excitations;
- Transient response, response spectra analysis;
- Vibration reduction and supporting problems.

Sound and noise:

- Operation noise, noise reduction by the design and geometry modifications;
- Acoustics, handling of noise sources;
- Noise reduction, isolation problems.

Fluids, gases:

- Fluid- structure interaction;
- Flow of viscous fluids (oil or cooling liquids);
- Pressure distribution in fluid films;
- Fluid friction;
- Lubrication problems;
- In internal combustion engines: or wheel and tire design: interaction of gas and structure.

Thermodynamics:

- Heat exchange between elements of a construction;
- Cooling problems,

– Heat conduction and convection, radiation.

Electromagnetism:

– Forces acting on elements working in magnetic field;
– Elements of electric motors, effects of the electromagnetic systems;

Fabrication and operation conditions:

– Operation and fabrication interferences;
– Errors, quality requirements, tolerances;
– Requirements and constraints that one must fulfil for the good fabrication and operation.

A large variety of possible application variations can be provided by the combination of the products and applied disciplines for the realistic analysis and optimization of designed products. The disciplines can be considered as constraints (in this case the objective function could be the weight, fabrication costs, load carrying capacity etc. or their combinations in multiobjective problems) or they can be taken into consideration as objective function, this way it is possible to design noise minimized constructions or moving structures or products having minimum power consumption or minimum friction power loss, higher load carrying capacity etc.

The examples and case studies shown in this paper can be found also as a combination of products and disciplines.

The qualification of a product means that all the most important technical parameters will be verified, where possible by using FEM studies and at the end of this process the product will receive a qualification as “ineligible” or “eligible” or “safely eligible”. This qualification can be continued if the economy, efficiency or optimality of an important product characteristic is qualified, in this case it could be possible to use quality levels as “non- optimized” or “inefficient”, “optimized” or “efficient” and “Pareto- optimized” or “multiobjective optimized”. These could be the possible levels of product qualification.

3. Case studies for qualification and optimization of products

3.1. Minimization of strains in electronic panels (improvement of product reliability)

During the testing procedure of electronic panels, the test signal is driven to the attaching points of the panel by using measuring needles. Since the testing program contains several input and output signals and measurements, in our days this process is performed by industrial robots and up to date programmable NC machines.

In this unified and robotized process 300–400 measuring needles can press the panel in one time, depending on the type of the panel and on the type of the needle. Each needle is built with a spring, in order to assure the correct contact with the panel. These springs are calibrated so that 3–5 N load is present at the contact point. It is easy to calculate, that in case of several hundred needles the panel is loaded with 1000–2000 N .Regarding the panel sizes, (160 mm length, 100 mm width and 1.6 mm thickness approximately, the size depends on the panel type) this is a high load. This load sometimes is causing so large deformation and strain values in the panel, that some local failures occur in the electronic elements assembled onto the panel, therefore a number of supporting pins is applied to decrease the deformation and strain (*Figure 1*.).

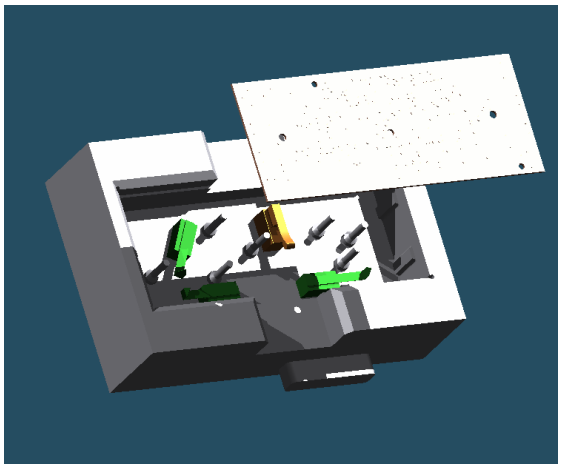


Figure 1. Supporting pins and the assembly of the panel into the measuring frame

Previous measurements and experiments show that a strain of value greater than a limit of $8x10^{-4}$ is dangerous for the local failure of the assembled elements. The experiments and measurements also show that the strain field in the panel is very sensitive for the arrangement and for the number of supporting pins (*Figure 2*.).

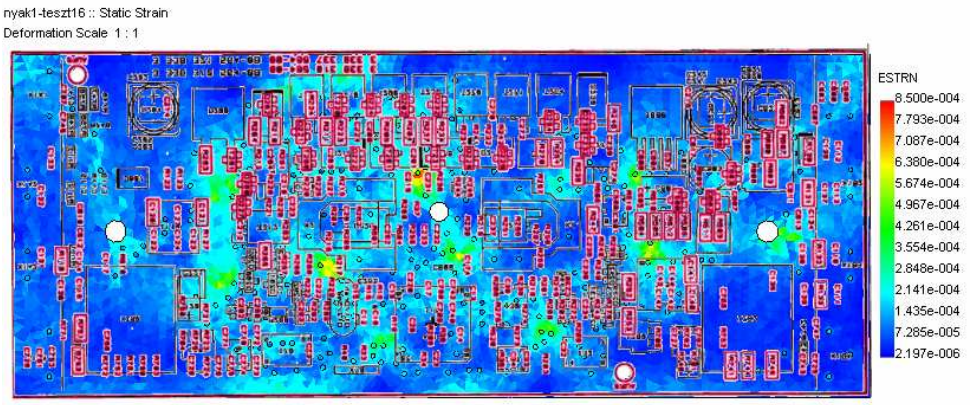


Figure 2. Strain contours shown on the assembly plan of electronic elements. This picture helps to decide which electronic element is in dangerous position

The assembly of the supporting pins sometimes can be very difficult, because electronic elements are assembled to the both sides of the panel, therefore one can find only a few place to apply supporting pins. This situation needs the optimisation of the number and

position of supporting pins used for decreasing the maximum strain on the panel under the limit value $8x10^{-4}$. In the solution of this task the strain field was determined by using finite element calculations and for the optimization the Genetic Algorithm was used. As results in the investigated cases, because of the optimal support arrangement the maximum strain value was decreased under $6x10^{-4}$ with same number of supports as before the investigation, or in other cases the limit of $8x10^{-4}$ is fulfilled with a number of supporting pins 20% smaller than before the investigation. These results are useful during the fabrication, because the smaller number of supporting pins can decrease the fabrication cost, the preparation time for the measurement can be shorter. Eliminating high strain values in the panel can increase the reliability or elongates the fatigue life of the product, and the number of waste products and user- complaints can be decreased considerably.

This case study was an example of improvement product reliability and economy by applying the results of a multidisciplinary optimization process (MDO). This study shows the advantages of an "optimized product".

3.2. Verification and qualification of the product

The second case study shows the example of product qualification, based on a finite element analysis (FEM).

In chemical plants, stack gases are eliminated (burnt) in a burner link. When the link is started up (lighting), this is an explosion; the inner pressure in this part of the pipeline will be very high. It is very important that the igniter should be verified against this pressure value if it will bear the strains, stresses and deformations occurring when starting the burner link. *Figure 3*. shows the igniter chamber, stress and deformation contours are in *Figure 4*.

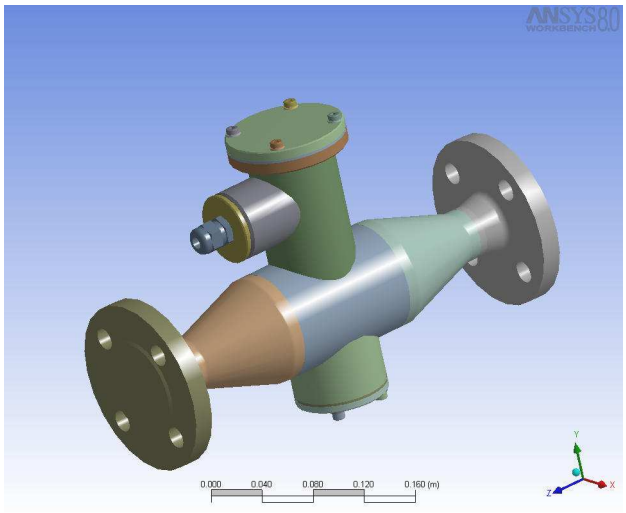


Figure 3. The igniter chamber

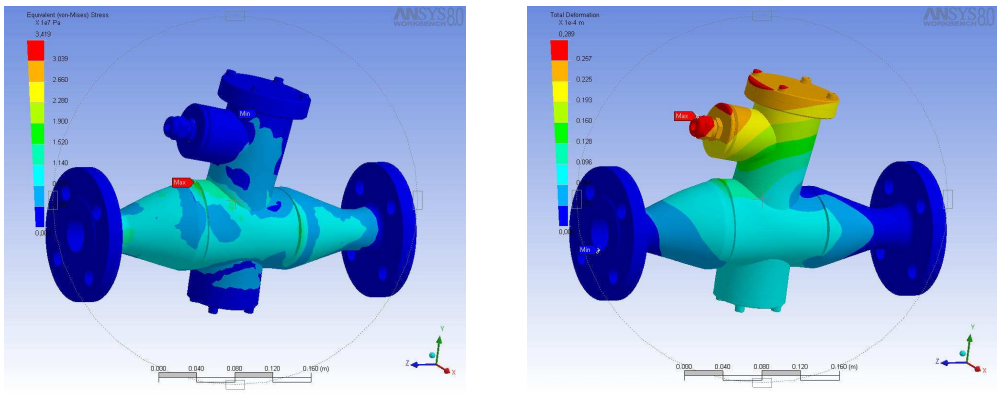


Figure 4. Stress (to the left) and deformation (to the right) contours of the igniter

On the basis of the finite element results, it was possible to draw the conclusion that the igniter is "safely eligible" under the operation circumstances during the lighting period. These results and some selected parts of the expert report were used by the manufacturer in the quality certificate of the product, which must be always part of the product documentation.

4. Student projects

4.1. Shape optimization of a product (pliers haft)

Figure 5. a) shows the initial three dimensional model of pliers, which has constant cross section shape regarding the haft. Shape optimization procedure in ANSYS DesignSpace program system shows the proposed material to eliminate (*Figure 5. b)*, in red colour), the designer has to redesign the structure, eliminating the unnecessary material and giving a new form concept to the product (*Figure 6.*).

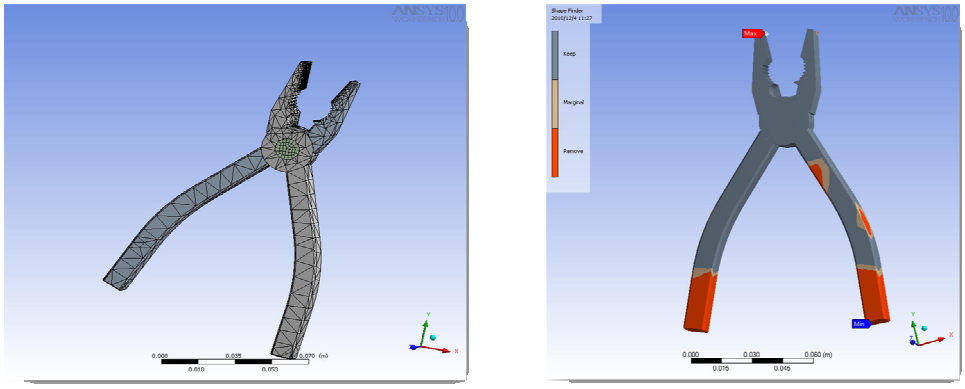


Figure 5. a) (Initial shape) and Figure 5. b) (materials to eliminate) of pliers model

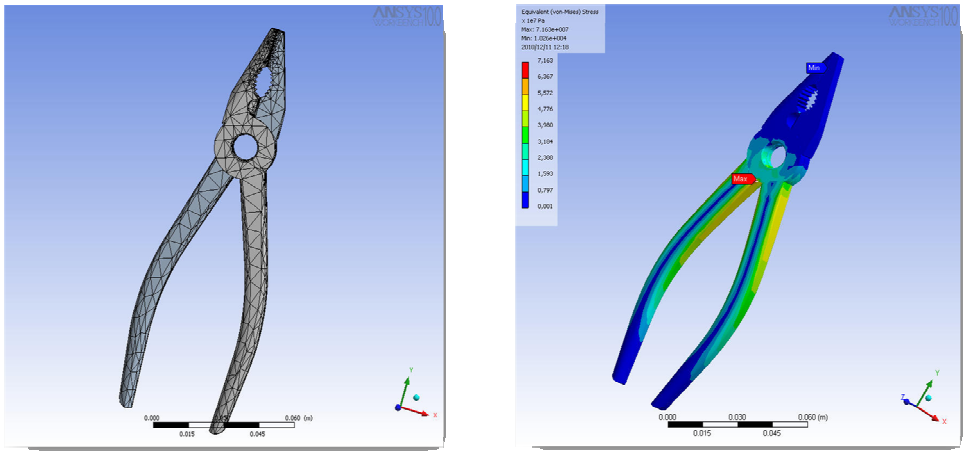


Figure 6. a) (New, improved form) and
Figure 6. b) (Stress state verification) of the product

As the result of the shape optimization procedure, 32% of the product material was spared. Finite element analysis of the new, optimized shape [*Figure 6. b*)] shows that the structure fulfils the operation requirements (in case of 200 N load, 71 Mpa is the maximum stress). The maximum deformation in this case is 0.2 mm.

4.2. Finite element analysis of a bar-chair

A new design of a bar- chair can be seen in *Figure 7. a),* having the shape of DNA spiral. On the basis of several finite element analysis, the modified design is shown in *Figure 8.*, while stress contours under the load can be found in Figure *7. b).* The structural behaviour of the DNA shape column invokes a lot of future development and research possibilities, therefore these investigations will be continued in the future, within the frames of Student Research Work (TDK).

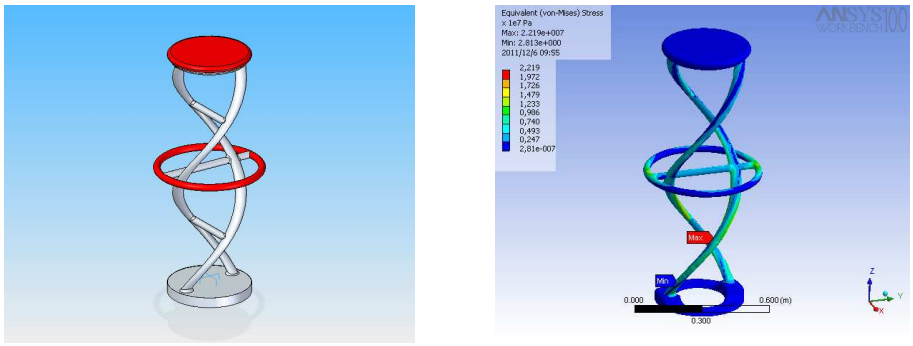


Figure 7. a) Original shape of the bar- chair and Figure 7. b) stress contours under the load caused by a sitting person

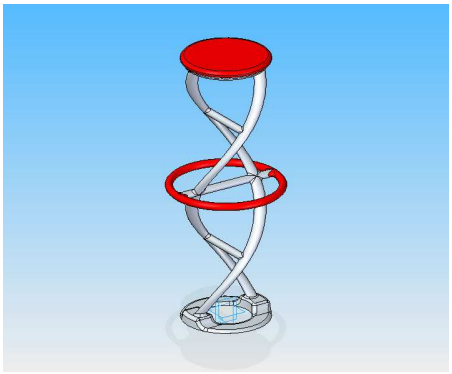


Figure 8. Modified design of the bar-chair after FEM analysis

5. Conclusion

On the basis of the definition of products, product quality and product qualification levels, the place and role of optimum design in product development process is described. Most important product characteristics and parameters are listed which can be subjected to optimization or multidisciplinary optimization (MDO) procedures. Case studies and numerical examples are shown for optimization, quality analysis, improvement and shape optimization of several industrial products and products designed by product designer students. The case studies and student works shown demonstrate the efficiency and advantages of applying FEM and MDO methods during the product design process.

Acknowledgements

"This work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund."

The author would like to thank the helps of Judit Pintér 4th and István Nagy, 3rd year Industrial Product and Art Designer BSc students studying "Product Simulation" course given by the author of this paper, at the Department of Machine and Product Design, during this course they build-up the three dimensional CAD and FEM models shown in Chapter 4.

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