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Večkriterialno optimiranje avtomobilske konstrukcije z uporabo metode končnih elementov

Multicriterial Optimization of a Car Structure Using a Finite-Element Method

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Pri razvoju motornih vozil poskušamo z uporabo računalniško podprtih numeričnih metod že v zgodnji razvojni fazi, pred izdelavo prvega prototipa, zagotoviti želene ciljne vrednosti dobe trajanja vozila, obnašanja vozila med trkom, zagotovitev udobja potnikov med vožnjo itn. Te ciljne vrednosti pa so odvisne od mnogih vplivnih parametrov. Napetost, ki se pojavi na analiziranem delu, je le ena od ciljnih vrednosti, ki jih je treba upoštevati pri razvoju. Zaradi zapletenosti današnjih numeričnih modelov se vse pogosteje uporabljajo samodejni postopki optimiranja konstrukcij vozil. Z uporabo parametričnih modelov MKE je mogoče ne samo ugotoviti, ampak tudi optimirati vplivne parametre, kakor so recimo debelina sten in konstrukcije površine avtomobilskega dna.

V prispevku je prikazan postopek večkriterialnega optimiranja avtomobilskih sestavov, ki temelji na sistematični kombinaciji tržnih in netržnih računalniških programov za izvedbo inženirskih analiz avtomobilskih konstrukcij po metodi končnih elementov (MKE). Ti programi so povezani z namenskimi vmesniki, ki omogočajo samodejno povezavo med njimi. Samo optimiranje temelji na genetskih ali gradientnih algoritmih. Odprtost razvitega sistema omogoča ugotavljanje in optimizacijo parametrov, ki vplivajo na ciljne vrednosti in izhajajo iz navidezno ustaljenih in dinamičnih analiz MKE, analiz trkov itn. Prikazan je tudi postopek redukcije več, med seboj praktično neodvisnih ciljnih vrednosti, na enotno ciljno vrednost, ki je nato optimirana. Praktični zgled ponazarja uporabnost razvitega postopka.

(Ključne besede: večkriterialno optimiranje, metode končnih elementov, topologija, genetski algoritmi, gradientni algoritmi)

Motor-vehicle development tends to be supported by the use of computer-aided numerical methods in the early development phase. Prior to manufacturing the first prototype it is required to ensure the requested vehicle-life expectancy, the vehicle's behaviour in a collision, passenger comfort while driving, etc. The listed target values depend on many other influential parameters. The stresses occurring on the analyzed part are only one of the target values that need to be considered in the development stage. Automated processes for the optimization of the vehicle construction are often applied due to the complexity of modern numerical models. Today, the use of parametric FEM models makes it possible to identify and optimize the main parameters, such as the wall thickness of the construction and the topological changes of the surface. This paper explains the procedure for a multicriterial optimization of a car's structure, based on a systematic combination of commercial and non-commercial computer programs performing engineering analyses of car constructions with the FEM. The computer programs are upgraded with specially designed interfaces that enable automated communication. The optimization itself is based on genetic and gradient algorithms. The openness of the system enables the identification and optimization of parameters, which influence the target values and stem from different static FEM analyses, dynamic FEM analyses, collision analyses, etc. The reduction procedure for more independent target values to a single target value that is later optimized is also explained. The example illustrates the applicability of the developed procedure.

(Keywords: multicriterial optimization, finite element methods, topology, genetic algorithms, gradient algorithms)

0 UVOD

Razvoj motornih vozil dandanes praktično temelji na uporabi računalniških inženirskih numeričnih metod. Metoda končnih elementov se že od 70. let uporablja v avtomobilski industriji za statične trdnostne preračune. V 80. in 90. letih pa je postala tudi standardna metoda za analizo obnašanja vozila med trkom, dinamike vozila in kot osnova za določanje dobe trajanja posameznih komponent vozila. Zaradi zapletenosti problemov se z vsakim od teh področij običajno ukvarja posebna skupina inženirjev. Ti morajo izsledke svojega dela nato prenesti v skupni izdelek. Le-ta je tako vedno zgolj kompromis rezultatov dela na več različnih področjih. Pri iskanju najboljših rešitev pa je smiselna uporaba samodejnih postopkov večkriterialnega optimiranja. Pričakovano je, da bodo v prihodnosti ti postopki postali standardno orodje razvojnega inženirja. Dandanes je največji problem v komunikacijski nezdružljivosti (prenos podatkov) posameznih računalniških programov, ki so potrebni za optimiranje.

Na trgu je dostopnih več tržnih računalniških sistemov, ki omogočajo samodejno optimiranje, in programov, ki omogočajo parametrizacijo mrež končnih elementov. Zaradi zapletenosti in raznolikosti problemov, ki jih analizirajo razvojni inženirji, pa za zdaj še ni na voljo splošnih vmesnikov, ki bi omogočali prenos podatkov med posameznimi računalniškimi programi za analize po metodi končnih elementov, programi za optimiranje in programi za parametrizacijo mrež končnih elementov. Zato je običajno še vedno treba za vsak analiziran problem narediti poseben vmesnik.

V prispevku je prikazan postopek optimiranja, ki je zasnovan tako, da ga je mogoče uporabljati v povezavi z različnimi programi in je zato primeren za večdisciplinarno optimiranje. Posamezni sestavni računalniški programi so lahko tudi netržni, kar omogoča dodatno znižanje stroškov.

0 INTRODUCTION

Computer-aided engineering is today one of the key technologies used to develop modern cars. The finite-element method has been used in the automotive industry since the early 1970s for static analyses. In the 1980s and 1990s the method became the standard tool for analysing dynamic, crash and fatigue problems. Because of the complexity of the analyzed problems every problem is normally analyzed by a separate group of engineers. Different groups of engineers then search for the best design. A modern approach to determine the best designs is to utilise a multicriterial optimization process. It is anticipated that the automated multidisciplinary optimization will become the standard optimization tool used by engineers. Currently, the biggest problem is the very low interoperability of the different computer programs that are required for the optimization process.

Many different software packages are available today, which allow for automated optimization and programs for morphing the finite-element model. Since engineers are usually working on different problems with very different finite-element solvers it is still necessary to specifically program the required interfaces between different FE programs, optimization programs and programs to parameterize the finite-element meshes.

This paper explains the procedure for multidisciplinary optimization based on a systematic combination of different commercial and non-commercial computer programs.

1 POSTOPEK VEČKRITERIALNEGA OPTIMIRANJA

Z matematičnega vidika je optimiranje iskanje najmanjše oziroma največje vrednosti določene funkcije p, en. (1), ki je pri večkriterialnem optimiranju odvisna od več vrednosti podfunkcij f_i, ki so odvisne od spremenljivk x_n:

1 MULTICRITERIAL OPTIMIZATION

Optimization is a search for the global minimum or maximum of the so-called objective function p (Eq. 1). In multicriterial optimization the objective function consists of many objective functions f_i for the design variables x_n:

$$p(f_i(x_1, x_2, ..., x_n)) \rightarrow_{\max}^{\min} ; i = 1,2,... N \quad (1).$$

Spremenljivke x_n so običajno omejene z zgornjo in spodnjo vrednostjo:

The range of each design variable x_n is limited by the upper and lower bound values:

$$x_{\min} < x_n < x_{\max} \tag{2}$$

Pri večkriterialnem optimiranju imajo posamične podfunkcije f_i svoje minimume pri različnih vrednostih spremenljivk x_n. Tako je minimum funkcije p zgolj kompromis ciljnih vrednosti podfunkcij f_i.

V strojništvu spremenljivke x_n imenujemo tudi optimizacijske oziroma projektne spremenljivke. Le-te so dveh vrst:

- Zvezne spremenljivke: spremenljivke so poljubna realna števila, ki so znotraj predpisanih območij (elastični modul, debelina rebra itn.).
- Diskretne spremenljivke: spremenljivke zavzamejo točno določene diskretne vrednosti, ki so znotraj predpisanega območja (debelina pločevine 1,0/1,2/1,4, premer vijaka M4/5/6 itn.). Diskretne spremenljivke so lahko tudi dvojiške (vrednost 0 ali 1; ojačitev je/ni, varilna točka je/ni itn.).

Ciljne vrednosti so lahko:

- Časovno neodvisne količine: napetosti [MPa] in pomiki [mm] pri statičnem preračunu, tipične lastne frekvence nihanja [Hz], masa [kg] itn.
- Časovno odvisne količine: frekvenčno spreminjajoče se vrednosti (pospeški pri vzbujanju s silo [mm/s²], raven hrupa [dB]), pospeški pri trku [mm/s²], sunek sile [N]).

Podfunkcije f_i so lahko določene kot razlika med želeno ciljno vrednostjo F_i in izračunano ciljno vrednostjo $f_i(x_n)$, kakor je to na primer prikazano v en. (3):

Each objective function f_i has its global minimum, usually at a different value of the design variable x_n. The solution strategy for a multicriterial optimization problem is to find the best compromise of target-design values of the objective functions f_i.

From the mechanical engineering point of view the design variables x_n can be classified as:

- Continuous variables: variables that vary continuously inside a defined interval (elastic modulus, thickness of a rib, etc.).
- Discrete variables: variables that vary with discrete values inside a defined interval. (sheet thickness 1.0/1.2/1.4, bolt thread M4/5/6, etc.). A discrete value can also have binary values (value 0 or 1; a rib is active or not, a weld spot is active or not, etc.).

The target values can be:

- Time-independent target values: static stresses [MPa] and displacements [mm], natural frequencies [Hz], mass [kg], etc.
- Time-dependent target values: frequency-dependent values (accelerations of force-excited structures [mm/s²], noise level [dB]), crash accelerations [mm/s²], force impulse [N]).

Objective functions f_i can be defined as the difference between the desired target value F_i and the calculated target value $f_i(x_n)$ (Eq.3):

$$f_i(x_1, x_2, \ldots, x_n) = \left(\frac{(f_i(x_n) - F_i)}{F_i} \right)^2 \tag{3}$$

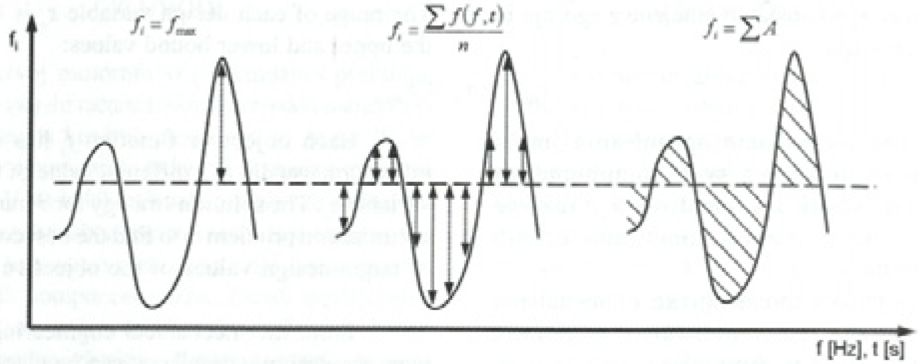
Medtem ko lahko razliko časovno neodvisnih vrednosti izračunamo neposredno, moramo frekvenčno in časovno spreminjajoče se vrednosti na določen način spremeniti v časovno neodvisne vrednosti. Najpogosteje to naredimo tako, da izračunamo razliko med največjimi vrednostmi, povprečno vrednost oziroma površino med dvema spreminjajočima se vrednostima (sl. 1).

Pomembnost določene podfunkcije f_i v postopku večkriterialnega optimiranja običajno poudarimo z utežnim koeficientom W_i en. (4), katerega vrednost poljubno izbiramo:

The differences for the time-independent variables can be directly calculated and used by the optimization program, while the time- and frequency-dependent variables have to be transformed to time-independent values. Usually, this is achieved by calculating the difference between the maximum and the minimum values, the average value or the area between the curves corresponding to the variation of the variables (Fig. 1).

The importance of the objective functions f_i in a multicriteria optimization is highlighted by the use of weighting factors W_i (Eq. 4), which can be arbitrarily defined:

$$p(f_i(x_1, x_2, \ldots, x_n)) = \sum_{i=1}^{m} W_i f_i(x_1, x_2, \ldots, x_n) \tag{4}$$



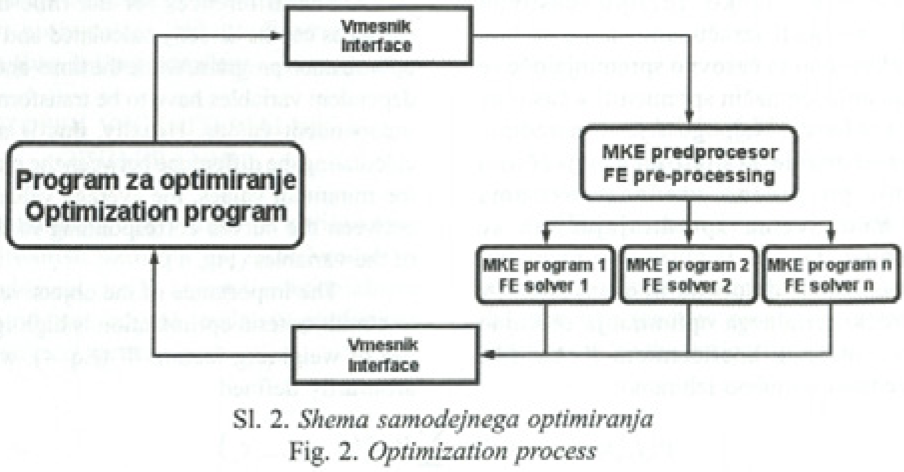
Sl. 1. *Časovno in frekvenčno spreminjajoče se ciljne vrednosti*
Fig. 1. *Time- and frequency-dependent target value*

Postopek samodejnega večkriterialnega optimiranja mora biti zasnovan tako, da je čim bolj odprt. Omogočati mora:
- uporabo različnih programov za optimiranje, mreženje in analize po metodi končnih elementov;
- programljivost vmesnikov, ki omogočajo povezavo med posameznimi programi,
- uporabnost v heterogeni sestavi računalnikov,
- neobčutljivost na izpad dela računalniškega sistema, s ponovnim samodejnim zagonom preračuna katerega rezultati niso bili ovrednoteni.

Na sliki 2 je prikazana shema samodejnega postopka optimiranja, ki je bil uporabljen v tem prispevku. Prenos podatkov med programi je izveden prek namenskih vmesnikov, ki so programirani v programskem jeziku Perl [3]. Programski jezik Perl je del operacijskega sistema Unix/Linux in omogoča preprosto ravnanje s besednimi datotekami in neposredno krmiljenje delovanja operacijskega sistema.

The process of multicriterial optimization has to allow for the use of very different programs. Therefore, the process has to satisfy the following conditions:
- it should be possible to use different optimization, meshing and solver programs;
- the user has to have the ability to program his or her own user interfaces between different programs;
- the process has to work on different computer operating systems;
- the process should be insensitive to the problems of the computer network and should allow for an automatic restart after a stopped optimization.

The optimization process explained in this paper is shown in Figure 2. The communication between different programs is achieved with the developed interface, which is programmed in the Perl computer language [3]. Perl is a part of every Unix/Linux distribution and allows for easy manipulation of text files and execution of system commands.



Sl. 2. *Shema samodejnega optimiranja*
Fig. 2. *Optimization process*

Uporabljeni postopek samodejnega optimiranja je naslednji. Namenski vmesnik zažene posebni program za pripravo podatkov (predprocesor) za analize MKE, ki na podlagi ustreznih vrednosti parametrov, določenih glede na trenutne ciljne vrednosti projektnih spremenljivk, spremeni topologijo analiziranega sklopa, ustvari in izpiše mrežo končnih elementov ter robne pogoje za različne programe MKE. Kakor hitro so na voljo proste licence potrebnih programov za analize po MKE, vmesnik zažene ustrezen program za analizo. Iz rezultatov analize namenski vmesnik nato izračuna vrednosti projektnih spremenljivk, ki so uporabljene v postopku nadaljnje optimizacije. Če rezultati analize MKE niso dostopni v nekem predpisanem času, vmesnik ponovno zažene program za analizo. Program za optimiranje izpiše ciljne vrednosti projektnih spremenljivk v tekstovno datoteko. Postopek se ponavlja, dokler ciljne vrednosti projektnih spremenljivk ne zadovoljijo ustreznega konvergentnega kriterija.

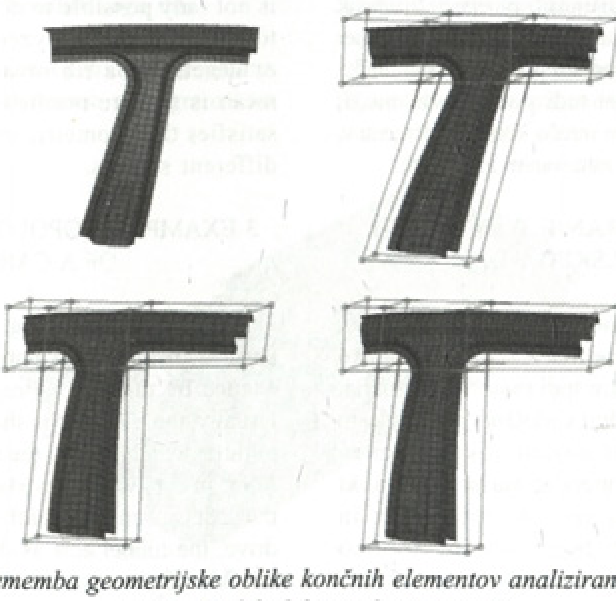
2 PARAMETRIZACIJA MREŽE KONČNIH ELEMENTOV

Pri konstruiranju motornih vozil se dandanes uporabljata predvsem dva programska paketa, Desault/Catia in UGS/NX. Njihova modula za mreženje in izpis datoteke z geometrijsko obliko analiziranega sklopa iz končnih elementov pa ne podpirata vseh funkcij, ki so potrebne za preračune z namenskimi programi za analize po metodi končnih elementov. Zato se

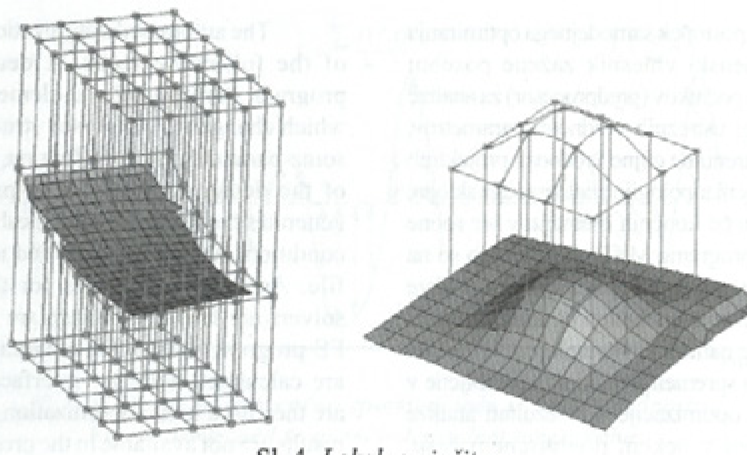
The automated optimization process consists of the following steps. A dedicated interface program starts the finite-element pre-processor, which changes the analysed structure according to some parameters, depending on the current values of the design variables. The pre-processor then generates the finite-element mesh and the boundary conditions, which are exported to an analysis start file. As soon as licenses for the finite-element solvers are free, the solvers are started. When the FE program returns the solution, the target values are calculated with an interface programme and are then used in the optimization programme. If the results are not available in the predefined time frame a new analysis is started. The optimization programme determines the optimal target values, which are then exported to a text file to be used in the next optimization step. The procedure is repeated until the target values of the design parameters reach a chosen convergence criteria.

2 PARAMETERISATION OF THE FINITE-ELEMENT MESH

Desault/Catia and UGS/NX are currently the two most used CAD packages in the car-development process. Their meshing modules do not support all the features of the finite-element solvers that are commonly being used by calculation engineers. Therefore, special programs are being used for meshing the CAD



Sl. 3. *Sprememba geometrijske oblike končnih elementov analiziranega sklopa*
Fig. 3. *Modified finite-element mesh*



Sl. 4. *Lokalne ojačitve*

Fig. 4. *Local reinforcement*

uporabljajo posebni programi s katerimi lahko zamrežimo CAD geometrijo analiziranega sklopa ter izpišemo diskretizirano geometrijsko obliko končnih elementov in robne pogoje.

Pri prenosu geometrijske oblike analiziranega sklopa iz programa CAD v predprocesor MKE se običajno izgubi celotna parametrizacija modela CAD. Zato programski paketi kakor sta Beta/ANSA [1] in Altair/HyperWorks [2] omogočajo parametrizacijo mrež končnih elementov. Z uporabo teh funkcij je mogoče avtomatizirati spremembo geometrijske oblike analizirane strukture (sl. 3 in 4), ne da bi uporabnik moral ročno popraviti mrežo oziroma ponovno predpisati robne pogoje.

Predprocesorji MKE ne omogočajo samo sprememb oblike in topologije analiziranega dela, ampak lahko program doda oziroma odstrani ojačitev, na primer rebro oziroma utor. Ker program pri spremembi oblike analiziranega dela ta del tudi ponovno zamreži, uporabljamo za vse analize mrežo končnih elementov, katere kakovost zadostuje zahtevanim kriterijem.

data and saving the finite-element mesh and boundary conditions in a native finite-element solver format.

When CAD data is being imported into the finite-element pre-processor, all CAD parameterisation is usually lost. Therefore, pre-processors like Beta/ANSA [1] and Altair/HyperWorks [2] have the ability to parameterize the finite-element mesh. With these functions it is possible to automate the process of redesigning the analyzed structure (Fig. 3, 4) without the need for any manual remeshing or redefining of the boundary conditions.

With the finite-element pre-processor it is not only possible to change the shape and the topology of the analyzed part but also activate or deactivate a rib or a groove. The morphed mesh is then re-meshed so that the new mesh satisfies the geometric mesh quality criteria for different solvers.

3 ZGLED: OPTIMIRANJE TOPOLOGIJE AVTOMOBILSKEGA DNA

Avtomobilsko dno (sl. 5) je v splošnem ravna ploskev, katere lastne frekvence nihanja lahko vzbuja neravna cesta kakor tudi motor avtomobila. Običajno ima dno v sredini vzdolžno grbino, ki jo imenujemo tudi predor in deluje kot ojačitev avtomobilskega dna. V predoru sta pri vozilu, ki ima pogon na zadnjih kolesih, menjalnik in kardanska gred. Med predorom in stranico avtomobila sta dve ojačitvi, na kateri se pritrdita sprednja sedeža.

3 EXAMPLE: TOPOLOGY OPTIMIZATION OF A CAR FLOOR

The car floor (Fig. 5) is generally a planar surface, from which natural frequencies can be excited by the car engine or the road roughness. Usually, the car floor is shaped with a tunnel in the middle, which acts as the reinforcement of the car floor. In cars with rear-wheel drive it also contains the gear box and the shaft. In cars with front-wheel drive, the tunnel acts as the reinforcement for the car floor. Between the tunnel and the side panel of a car are two supports for mounting the driver seat.

Avtomobilsko dno lahko razdelimo na več območij, ki jih obravnavamo ločeno. Takšna območja morajo navadno zadovoljiti naslednje zahteve:

- Prva lastna frekvenca vsakega območja ne sme biti v resonanci s frekvenco delovanja motorja.
- Največji pomik in napetost, ki sta posledica mase oseb in tovora v vozilu, morata biti pod izbranima ciljnima vrednostima.

Ojačitev dna s privaritvijo dodatnih ojačitev dandanes zaradi velikih stroškov ne pride več v poštev. Pri izdelavi dna se zato v posamezna območja običajno vtisne določen vzorec, ki to polje ojača.

Priporočene oblike ojačitvenih vzorcev so opisane v klasični literaturi, ki izhaja še iz 50. let preteklega stoletja ([4] in [5]). Nekatere novejše študije pa so pokazale, da je mogoče s samodejnim optimiranjem topologije ojačitev dna doseči mnogo boljše rezultate [6]. Za optimiranje topologije ojačitev obravnavane v tem prispevku, je bil uporabljen programski paket ALTAIR/HyperWorks. Rezultati programskega paketa za analizo sistemov po metodi končnih elementov MSC/Nastran [7] so programskemu paketu ALTAIR/HyperWorks osnova za optimiranje oblike vzorca ojačitev. Temu programskemu paketu lahko predpišemo zgolj želeni pomik, napetost in lastno vrednost nihanja. Ni pa mogoče uporabiti rezultatov iz več ko enega programskega paketa za analizo sistemov po metodi končnih elementov. Tudi sam algoritem, ki ga program uporablja, ni javno dostopen.

3.1 Parametrizacija avtomobilskega dna

Topologija pločevine 4 avtomobilskega dna na sliki 5 je bila parametrizirana s programskim

The car floor can be partitioned into several regions, which can be analyzed separately. Each region has to satisfy the following:

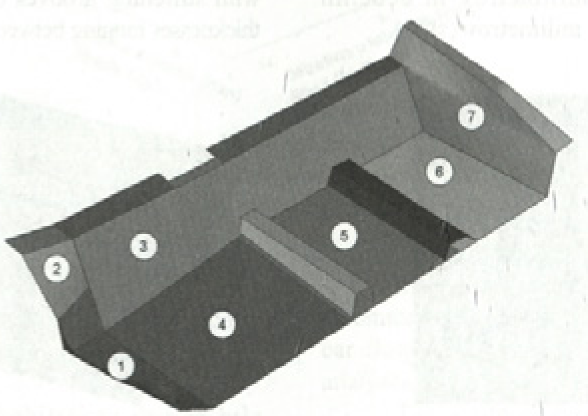
- The first natural frequency of each floor region should not be excited by the car engine.
- Displacements and stresses due to the passengers' and cargo weight should be under the target values.

The costs of welding reinforcements to the car-floor panels is too high and is not being used in modern car design any more. Instead, different groove patterns are being pressed into the panels during their production process to stiffen the panels.

The classical forms of stiffening grooves were developed in the 1950s [4, 5]. Newer studies have shown that the panel stiffness can be increased with the use of automated optimization of the stiffening groove patterns [6]. The program package ALTAIR/HyperWorks was used for the topology optimization of the car-floor panels reported in this paper. The numerical results obtained by the finite-element solver MSC/Nastran [7] are the basis of the car-floor panel optimization by the ALTAIR/HyperWorks. Only the displacements, stresses and the first natural frequency can be defined as target values. And only the results of one finite-element solver can be used for the optimization. Also, the optimization algorithm is not publicly available.

3.1 Parameterization of the car floor

The topology of the floor region 4, shown in Figure 5, has been parameterized using the Beta/ANSA



Sl. 5. *Analizirano avtomobilsko dno in razdelitev na posamezna območja*
Fig. 5. *Analyzed car-floor panels and partitioning regions*

paketom Beta/ANSA, kar je prikazano na sliki 4. Definirano je bilo 250 krajevnih ojačitev, ki so bile visoke med 0 in 20 mm. Kot spremenljivka je bila definirana še debelina pločevine med 0,5 in 2,0 mm. Za optimiranje je bil uporabljen programski paket OptiSlang [8] in program MKE MSC/Nastran. Ciljne vrednosti so bile izračunane iz rezultatov statične analize ter analize lastnih vrednosti (prva lastna frekvenca nihanja, togost, masa in največja napetost na pločevini) po MKE. Prva lastna vrednost pločevine 4 je bila določena s kriterijem MAC. Pločevina je bila optimirana v sestavu karoserije, saj je bilo iz predhodnih analiz razvidno, da so rezultati drugačni, če je pločevina analizirana brez upoštevanja vpliva togosti celotne karoserije.

3.2 Rezultati analize

Za optimiranje sta bila uporabljena genetski algoritem in algoritem RSM. V prvi fazi je bilo izvedeno optimiranje topologije pločevine z genetskim algoritmom z 20 generacijami optimiranja. Izvedenih je bilo 400 analiz po metodi končnih elementov. Rezultat optimiranja topologije pločevine je prikazan na sliki 6-levo. Na podlagi tako dobljene topologije je bila izdelana konstrukcijska rešitev, slika 6-desno.

V drugi fazi je bilo z algoritmom RSM raziskano, kako sprememba debeline pločevine in višine ojačitvenega vzorca vpliva na ciljne vrednosti (sl. 7).

Analiza je pokazala, da je najboljši kompromis med težo in togostjo pločevine dosežen pri višini ojačitve 10 milimetrov in debelini pločevine med 1,0 in 1,5 milimetrov (sl. 8).

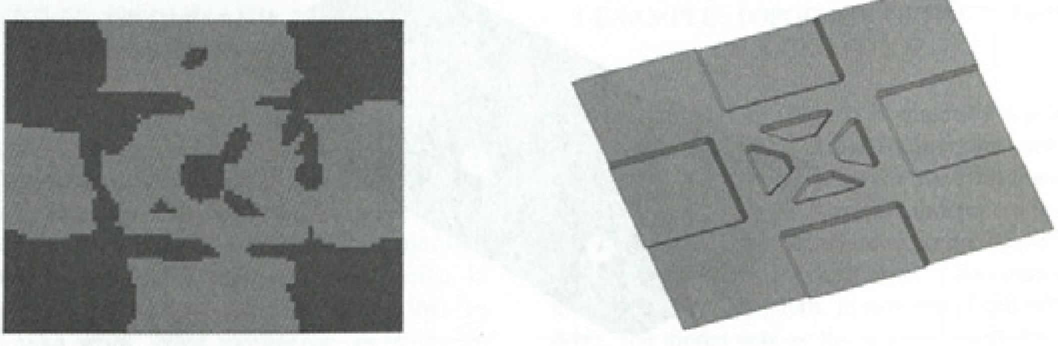
program, as shown in Figure 4. A total of 250 stiffening grooves were defined, with their height ranging between 0 and 20 mm. The thickness of the metal sheet was also defined as a design variable with a range between 0.5 and 2.0 mm. The OptiSlang [8] computer programme was used for the optimization and the finite-element solver MSC/Nastran, for the computational engineering analyses. The target values of the objective function were computed from static and natural frequency analyses (the first natural frequency, the stiffness, the mass and the maximum stress). The first natural frequency of panel 4 was evaluated with the help of the Modal Assurance Criterion (MAC). The floor panel was analyzed in the framework of the complete car-body analysis. Initial analyses have shown that the panel stiffness differs significantly if the car body's influence is not considered.

3.2 Analysis results

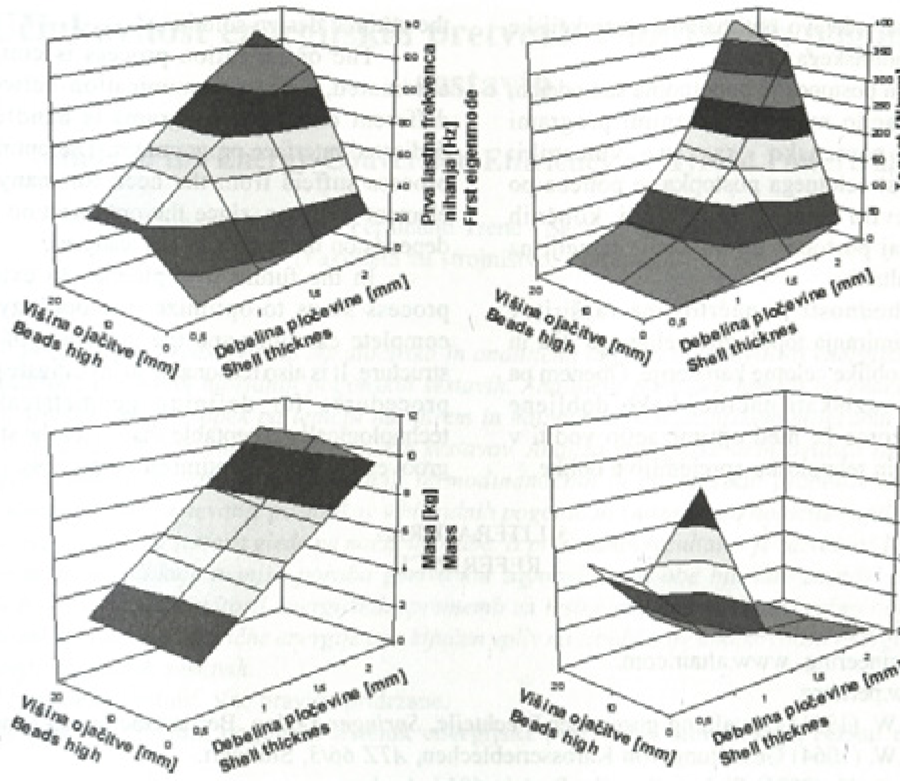
Genetic and approximation RSM algorithms were used for the optimization. In the first phase the optimization of the floor-panel topology with a genetic algorithm and 20 generations was used. A total of 400 finite-element analyses were computed. The results of the topology optimization are shown in Figure 6 (left-hand side). These results served as a guideline to generate a panel design solution proposal, Figure 6 (right-hand side).

During the second phase the RSM algorithm was used to investigate the influence of the metal-sheet thickness and the stiffening-groove height on the design values (Fig. 7).

The results of the optimization study showed that the highest stiffness for the floor panel can be achieved with stiffening grooves of 10 mm and sheet-metal thicknesses ranging between 1.0 and 1.5 mm (Fig. 8).

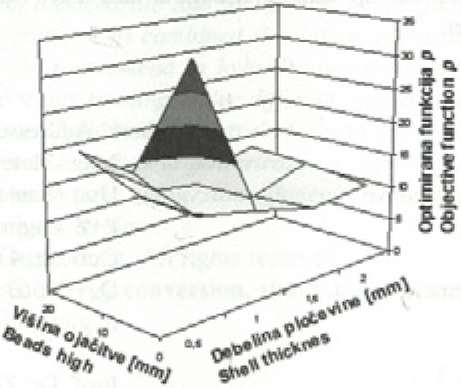


Sl. 6. *Rezultati samodejnega optimiranja in konstrukcijska rešitev*
Fig. 6. *Result of the automatic optimization and the proposed design solution*



Sl. 7. *Ciljne vrednosti podfunkcij f_i*

Fig. 7. *Target values of the part objective functions f_i*



Sl. 8. *Vrednosti funkcije p*

Fig. 8. *Objective function p*

4 SKLEP

V delu je prikazan postopek samodejnega večkriterialnega optimiranja topologije ojačitev avtomobilskega dna z uporabo rezultatov analiz po metodi končnih elementov.

Topologija avtomobilskega dna je bila optimirana na podlagi parametriziranega modela končnih elementov. Rezultati optimiranja so bili

4 CONCLUSION

This paper explains the procedure for an automated multicriterial optimization process of a car floor by using the results of finite-element analyses.

The optimization was performed by using the parameterized finite-element model of the car floor. The optimization results were used to define uporabljeni za izdelavo optimalne konstrukcijske rešitve avtomobilskega dna.

Celoten postopek je popolnoma samodejen, saj komunikacijo med posameznimi programi opravljajo namensko razviti vmesniki. Pomanjkljivost celotnega postopka je potreba po velikem številu analiz po metodi končnih elementov, saj postopek optimizacije temelji na njihovih rezultatih.

V prihodnosti je načrtovana razširitev postopka optimiranja topologije celotnega dna in geometrijske oblike celotne karoserije. Obenem pa je smiselno raziskati načine, kako dobljene ojačitvene vzorce že med optimizacijo voditi v geometrijsko in tehnološko sprejemljive oblike.

the optimal design solution.

The optimization process is completely automated, since communication between the different computer programs is handled with dedicated interface programmes. The optimization process suffers from the need for many finite-element analyses, since the optimization process depends on the results of the analyses.

In the future it is planned to extend the process so as to optimize the topology of the complete car floor and the geometry of the car structure. It is also reasonable to investigate possible procedures for defining geometrically and technologically acceptable shapes for the stiffening grooves during the optimization process.

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