Rekonstrukcija odvaljnega bata zračne vzmeti

Reconstruction of an Air-Spring Piston

Tomaž Bešter

Odvaljni bat, ki ga izdeluje Goodyear EPE (Engineered Products Europe), prenese vse obremenitve, ki jih zahtevajo evropski tehnični standardi , v primeru, ko je podprt po celotni spodnji površini. Če je odvaljni bat podprt samo po delu površine, ne prenese vseh zahtevanih obremenitev. Za rešitev problema je bila najprej narejena trdnostna analiza odvaljnega bata, nato pa je bil bat spremenjen, tako da je zdržal vse zahtevane obremenive.
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(Ključne besede: vzmeti zračne, bati odvaljni, analize trdnostne, modifikacije)

An air-spring piston, produced by Goodyear EPE (Engineered Products Europe), is able to withstand all the loads that are required by European Engineering Standards when it is supported on its entire lower surface. When the piston was only supported on a part of the lower surface it was not able to withstand all the loads. To solve this problem we made a strength analysis of the existing piston. The piston was then modified so that it was able to withstand all the required loads.
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**(Keywords: air springs, pistons, strength analysis, modifications)**

0 OBREMENITVE ODVALJNEGA BATA

Zračna vzmet [7] je sestavljena iz odvaljnega bata, meha, blažilnika in zgornje plošče (sl. 1). Evropski tehnični standardi [6] za zračne vzmeti predpisujejo, da mora vzmet prestati dinamični preskus, preskus na utrujanje in preskus na razpočni tlak.

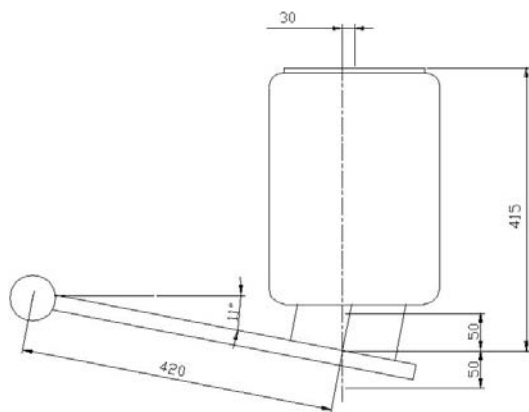### 0 LOADS ON AN AIR-SPRING PISTON

An air-spring [7] is made of an air-spring piston, a skin, a rubber damper and an upper plate. According to European Engineering Standards [6] an air-spring piston has to pass a dynamic test, a static test and a pressure test (Fig. 1).
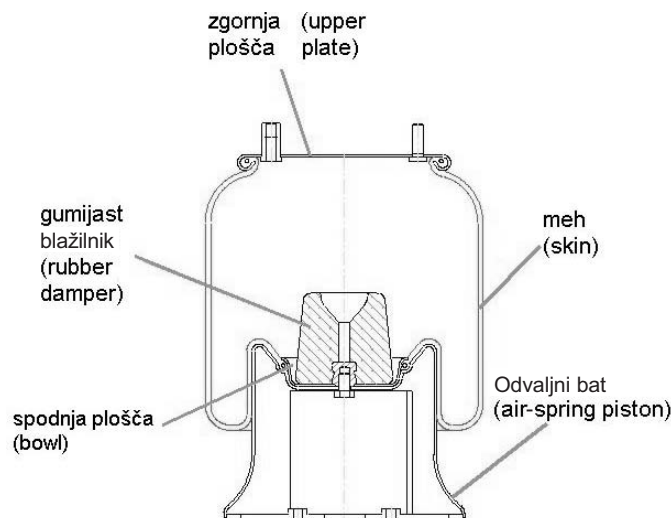
Sl. 1. *Odvaljni bat zračne vzmeti*
Fig. 1. *An air-spring piston*

Pri dinamičnem preskusu mora zračna vzmet prestati tri milijone ponovitev pri spremembi višine vzmeti 50 mm, tlaku v mehu 6 bar in frekvenci 1,25 Hz. Vpetje vzmeti je prikazano na sliki 2. Izkušnje kažejo, da v tem preskusu odvaljni bat običajno ni kritično obremenjen, ampak se poškodbe zaradi utrujanja navadno pojavijo na mehu, kjer pride do spuščanja zraka.

Preskus na razpočni tlak zahteva, da se meh zračne vzmeti pri višini vzmeti 300 mm napolni z vodo pod tlakom 18,2 bar. Pri tem tlaku ne sme priti do poškodbe meha ali odvaljnega bata.
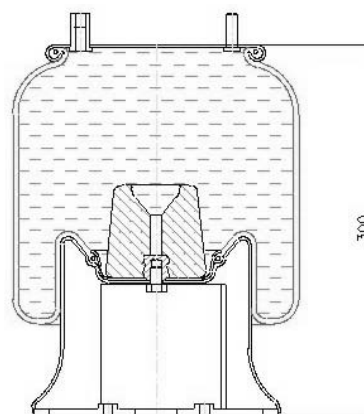
During the dynamic test the air spring has to withstand three million cycles at an amplitude of 50mm, a pressure of 6 bar and a frequency of 1.25 Hz. The suspension of the spring is shown in Fig. 2. Our experiences show that in this case the piston is usually not critically loaded, while the damage usually occurs to the skin, which causes air to leak from the spring.

The pressure test (Fig. 3) requires that the air spring is filled with water at a pressure of 18.2 bar while the spring is 300mm high. This pressure must not cause any damage to the air spring.

Sl. 2. *Dinamični preskus*
Fig. 2. *Dynamic test*

Sl. 3. *Preskus na razpočni tlak*
Fig. 3. *Pressure test*

Statični preskus zahteva, da morata odvaljni bat in blažilnik zdržati obremenitev s silo 180 kN. Pri tem preskusu se preskušata samo odvaljni bat in blažilnik vzmeti. Vpetje odvaljnega bata je odvisno od izdelovalca podvozja, tako je lahko podprt po celotni spodnji površini, ali pa je previsno podprt, kakor prikazuje slika 4.

Odvaljni bati, ki jih izdeluje Goodyear EPE, so izdelani iz umetnih mas ali jekla. Za plastične bate, ki jih izdeluje Goodyear EPE, se je pri preskusih izkazalo, da prenesejo vse obremenitve, ki jih terjajo evropski tehnični standardi, razen statičnega preskusa s

The static test requires that an air-spring piston and damper withstand a loading of 180 kN. In this way only the piston and damper are tested. The suspension of the piston depends on the undercarriage. The undercarriage manufacturers use two ways of supporting the piston, some support it on the whole lower surface, and others only on a part of the lower surface, as shown in Fig. 4.

The air-spring pistons manufactured by Goodyear EPE are made of plastic materials or steel. Tests of the plastic pistons have shown that they pass all the tests except the static ones, when only a
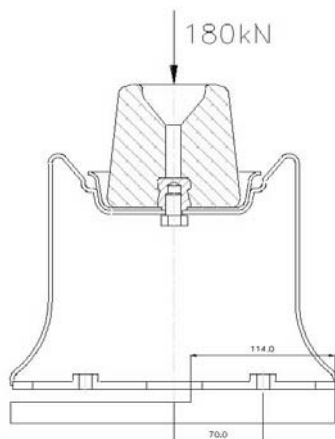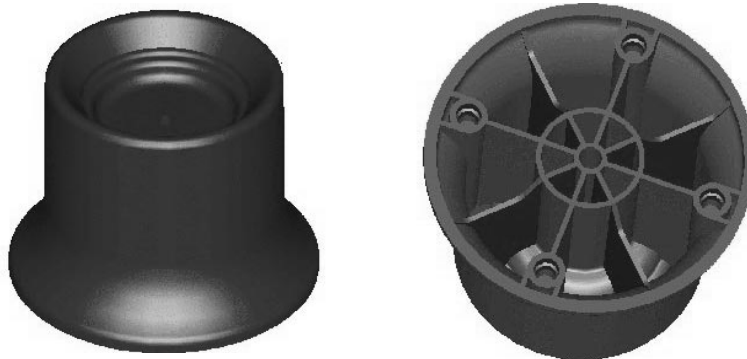

Sl. 4. *Statični preskus s previsnim vpetjem bata*
Fig. 4. *Static test*

previsnim vpetjem. Za rešitev problema je bila najprej narejena trdnostna analiza sedanje konstrukcije, pri obremenitvi, kakršno predpisuje statični preskus, in previsnem vpetju.

part of the lower surface is supported. To solve this problem a strength analysis of the existing piston for a static test was carried out for an overhanging support.

1 TRDNOSTNA ANALIZA SEDANJE KONSTRUKCIJE

1 STRENGTH ANALYSIS OF THE EXISTING PISTON

Trdnostna analiza sedanje konstrukcije (sl. 5) je bila narejena z uporabo metode končnih elementov v programskem paketu Ideas [3]. V analizi se ni upoštevalo, da zaradi prevelike obremenitve pride do plastifikacije in porušitve, zato s to analizo nismo dobili natančnih napetosti na batu, ampak ta analiza razkrije mesta, na katerih se pojavijo največje napetosti, in da kriterij za primerjavo različnih variant. V modelu končnih elementov ([2] in [4]) so bili uporabljeni desetvozliščni piramidni elementi. Ker je odvaljni bat simetričen, je bilo mogoče modelirati samo polovico bata.

A strength analysis of the existing piston (Fig. 5) was made using the finite-element method and the Ideas computer program [3]. The analysis did not consider that plastification and perhaps even destruction might occur due to overload; therefore, this analysis does not provide the exact stresses on the piston, but only the location of the maximum stress, and this gives the criterion for a comparison of the different designs. In the finite-element model, ten-node tetrahedron elements were used ([2] and [4]). Since the piston is symmetrical, we only need to model half of it.

Sl. 5. *Sedanja konstrukcija*
Fig. 5. *Existing air-spring piston*

Bat je na obeso v primeru previsnega vpetja pritrjen samo z dvema vijakoma in na spodnji ploskvi podprt na manj ko polovici površine. Matica vijaka je jeklena in je vstavljena v bat med brizganjem umetne mase. Zaradi svoje oblike matica preprečuje pomikanje bata v navpični smeri na spodnjem robu matice, pa tudi v vodoravni smeri. Ker bi modeliranje matice terjalo lokalno zgostitev mreže in s tem povezano podaljšanje že tako dolgega računanja, v modelu končnih elementov ta matica ni bila modelirana, ampak so bile na površini, kjer matica preprečuje pomik v navpični smeri, postavljene podpore v tej smeri. Na sliki 6 so prikazane podpore na mestu, kjer je v bat iz umetne mase vstavljena matica (v smereh, kjer so omejitve pomika, so puščice). Takšen model ne upošteva elastičnosti vijaka in matice, vendar je modul elastičnosti vijaka in matice bistveno večji od modula elastičnosti umetne mase, ki obdaja matico, zato je takšna poenostavitev dovoljena.

In the case of the overhanging support the piston is screwed down with only two bolts and supported on less than half the lower surface. The nut is made of steel and is inserted into the piston. Because of its shape the nut does not allow movements in the vertical and horizontal directions. Modelling of the nut would require condensation of the mesh around the nut; this would result in a considerable increase in the calculation time. Therefore, in the finite-element model the nut was not modelled; however, restraints were set in the vertical direction in the place where the nut restrains the piston. Fig. 6 illustrates this particular case (the arrows show the directions in which the displacements are restrained). Such a model does not consider the elasticity of the bolt and of the nut, but because the bolt and the nut have a much greater module of elasticity such a simplification is admissible.

Bat je podprt z jeklenim kvadrom na enako veliki površini kakor v primeru previsnega vpetja. Jeklen kvader je po vsej svoji spodnji površini podprt v navpični smeri. Takšno vpetje je zelo podobno

The piston is supported with a steel block on the same surface as shown in Fig. 4. The steel block is supported in the vertical direction over its entire lower surface. Such a suspension is very similar to
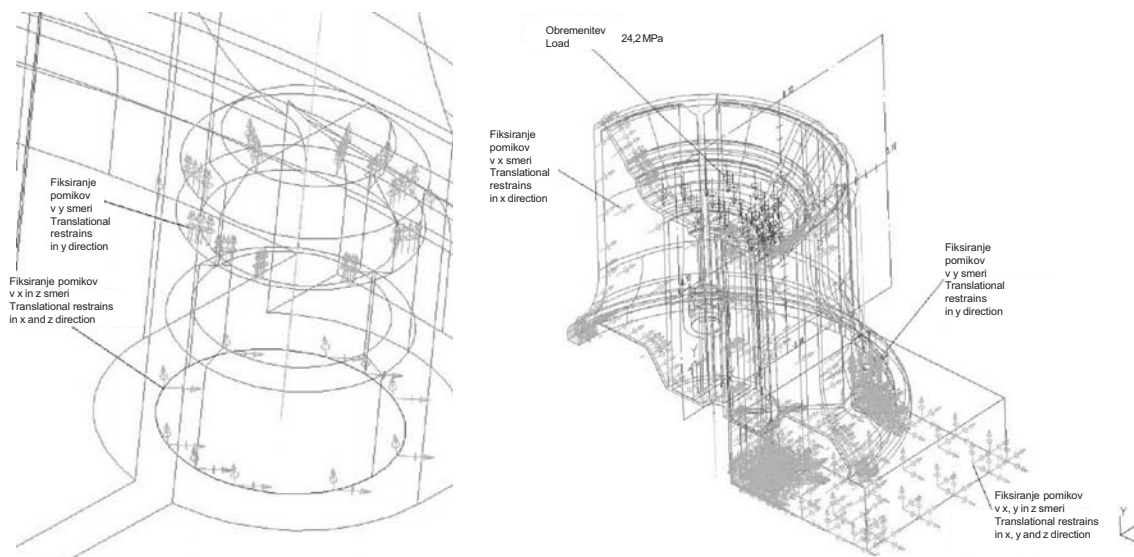
Sl. 6. *Podpore*
Fig. 6. *Restraints*

tistemu na preskuševališču za statični preskus. Poleg že prej opisanih podpor je treba, zaradi simetrije, namestiti podpore tudi pravokotno na ravnino prereza bata. Bat je od kvadra oddaljen za 1mm zato, da se lahko med kvader in bat postavijo tako imenovani elementi špranje, ki povezujejo vozlišča kvadra in bata. Elementi špranje prenašajo samo tlačne sile, ne pa tudi nateznih, tako da dovoljujejo povečevanje razmika med batom in kvadrom. Model končnih elementov je prikazan na sliki 7.

Pri dejanskem preskusu je odvaljni bat obremenjen s predpisano silo prek gumijastega blažilnika. Modeliranje tega blažilnika bi zopet močno povečalo število končnih elementov v modelu in s tem podaljšalo čas računanja. Poleg tega je blažilnik iz gume, ki je zelo deformljiva, kar pomeni, da ne bi več veljala predpostavka, da so na modelu samo majhni pomiki. Poleg tega ima guma nelinearno

the suspension with the static test. In addition to the previously mentioned restraints, it is necessary to set restraints perpendicular to the section plane of the piston. All the restraints are shown in Fig. 6. The piston is set 1 mm above the steel block, so that the gap elements can be placed between the piston and the block. The gap elements carry only the compressive forces and therefore allow stretching of the nodes on both surfaces in the contact. The finite-element model is shown in Fig. 7.

During the actual test the piston is loaded with the prescribed force on the rubber damper. Modelling of this damper would substantially increase the number of elements and thus prolong the already long calculation time. Furthermore, the damper is made of rubber, which is very deformable, and so the assumption about small displacements would no longer be true. The rubber also has a non-linear char-
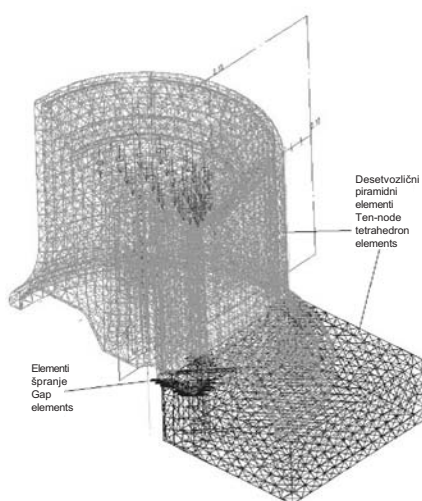
Sl. 7. *Model končnih elementov*
Fig. 7. *Finite-element model*
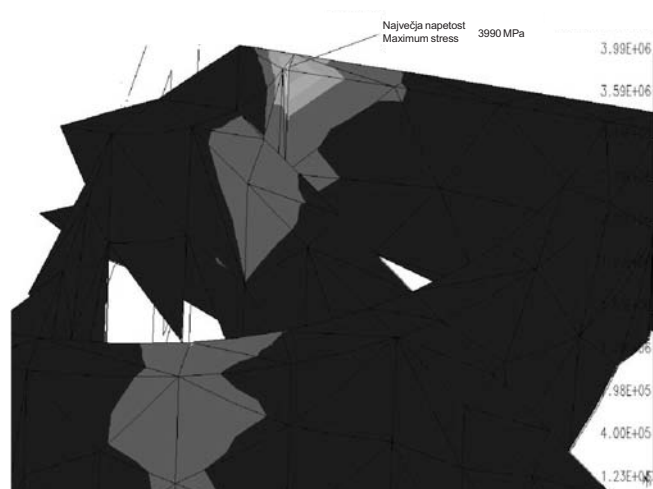
Sl. 8. *Največja primerjalna napetost*
Fig. 8. *Maximum equivalent stress*

karakteristiko v diagramu $\sigma - \varepsilon$, kar bi zopet močno podaljšalo čas računanja. Modela končnih elementov, ki bi upošteval vse zgoraj naštete fizikalne pojave, računalnik, ki je bil na voljo, ni bil zmožen rešiti, zato je bil narejen poenostavljen model, na katerem se je sila enakomerno porazdelila po površini, na kateri blažilnik nalega na bat. Ker gre za razmeroma zgoščen vnos sile, ta poenostavitev ne vpliva bistveno na napetostno stanje.

Odvaljni bat je iz umetne mase AG3(H)(K), ki ji je dodano 30% steklenih vlaken, ta so enakomerno porazdeljena po celotni prostornini, zato lahko predpostavimo, da je material izotropen. Material izdeluje General Electric [1]. Materialne lastnosti so povzete po katalogu izdelovalca in Machinery's Handbook [5]:

Natezna trdnost:	$\sigma_M = 170\,\text{MPa}$
Modul elastičnosti:	$E = 9800\,\text{MPa}$
Gostota:	$\rho = 1{,}36\,\text{g/cm}^3$
Poissonov količnik	$\nu = 0{,}3$

Meja plastičnosti ni podana, vendar lahko rečemo, da je enaka natezni trdnosti, ker ima material skoraj povsem linearno karakteristiko v diagramu $\sigma - \varepsilon$.

Rezultati linearne analize z metodo končnih elementov so smiselni samo v primeru, da napetosti ne presežejo meje plastičnosti. V obravnavanem problemu so rezultati (sl. 8) analize močno presegli mejo plastičnosti, zato napetosti, ki so prikazane na slikah, niso stvarne, saj prej pride do plastifikacije in porušitve. Lahko pa iz teh slik ugotovimo, kje so mesta, kjer se pojavijo največje napetosti. Na sliki 8 se vidi, da se pojavi največja primerjalna napetost na robu površine, kjer je bat podprt s kvadrom, hkrati pa je to tudi mesto, kjer je rebro povezano z notranjim valjem.

2 SPREMINJANJE OBLIKE VALJA, DA BI ZADOSTILI ZAHTEVAM STANDARDA

Zunanja oblika valja se ne sme spreminjati, saj bi to pomenilo spremembo karakteristike vzmeti, zato lahko na batu spreminjamo samo lego in debelino reber. Prav tako ne smemo spreminjati lege pritrdilnih matic. Najprej se je spremenila lega reber, tako da so ležala pravokotno na previsni rob (sl. 9), da se je obremenitev porazdelila na več reber. Poleg geometrijske oblike so se na modelu končnih elementov spremenili tudi elementi v dotiku. Namesto tako imenovanih elementov špranje so se med obe dotikalni površini na mesta, kjer pričakujemo dotik med površinama, postavili togi elementi. Uporaba togih elementov bistveno skrajša čas računanja. Razlike v rezultatu med modelom s togimi elementi in modelom z elementi špranje so minimalne, če pravilno napovemo mesto, kjer pride do dotika površin. Zato so se v trdnostnih analizah vseh različic uporabljali

acteristic in the $\sigma\text{-}\varepsilon$ diagram. Consideration of all these phenomena would require too much time for the computations, so a simplified model was made, where the prescribed force was uniformly distributed over the lower surface of the damper. Because we have a relatively concentrated transference of the force, this simplification does not significantly influence the tensions in the piston.

The air-spring piston is made of a plastic material called AG3 (H)(K), which has 30% of glass fibres that are uniformly distributed over the entire volume, so that the material can be considered isotropic. The material is produced by General Electric, and its properties, reproduced from the General Electric [1] catalogue and Machinery's handbook, are as follows [5]:

Tensile strength:	$\sigma_M = 170\,\text{MPa}$
Modulus of elasticity:	$E = 9800\,\text{MPa}$
Density:	$\rho = 1.36\,\text{g/cm}^3$
Poisson's ratio:	$\nu = 0.3$

The yield stress is not given, but since the material has an almost linear characteristic we can assume that it equals the tensile strength.

The linear finite-element method gives us reasonable results only when the tensions do not exceed the yield stress. In our case the yield stress was exceeded. Therefore the stresses that are shown in Fig. 8 are not the true ones – because destruction would occur first. However, we can locate the most critical places where the maximum stresses occur. We can see in Fig. 8 that the maximum equivalent stress occurs on the edge of the surface, where the piston is supported with a solid block. At the same time this is the place where the rib is connected to the inner cylinder.

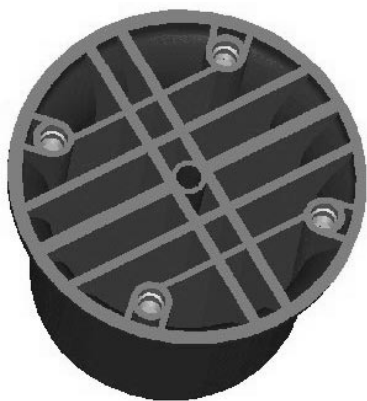## 2 MODIFYING THE SHAPE OF THE PISTON TO SATISFY THE NEEDS OF THE STANDARD

The external shape of the piston should not be changed, as this would change the characteristic of the air-spring piston; therefore, we can only change the position and thickness of the ribs. The position of the nuts should also not be changed. Firstly, the position of the ribs was changed so that they were perpendicular to the edge of the block. Secondly, the type of finite elements in the contact was changed. Instead of gap elements rigid elements were placed on the nodes where we anticipated contact between the surfaces. The use of rigid elements significantly reduced the computation time. The difference between the model with a gap and the model with rigid elements is minimal, that is if the nodes where the contact of the two surfaces occurs are correctly predicted. That is why in strength calculations of all the variants rigid elements were used, except for the last

togi elementi, razen pri zadnji varianti, ki se je preverila tudi z modelom z elementi špranje. Rezultati trdnostne analize (sl. 10) kažejo, da so se napetosti bistveno zmanjšale, še vedno pa so večje od natezne trdnosti, zato bi se ta izvedba bata na preskusu porušila. Še vedno je najbolj problematična zgostitev napetosti na mestu, kjer je rebro povezano z notranjim valjem.
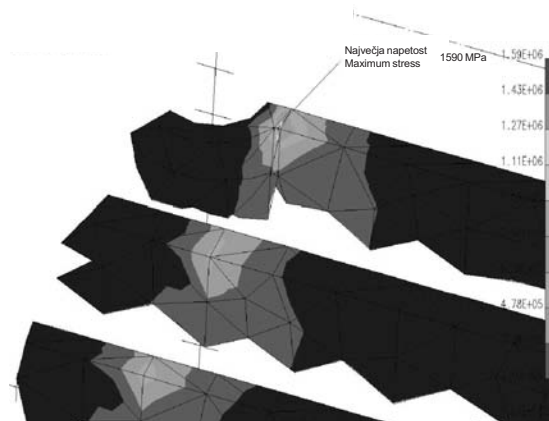
variant, which was checked with gap elements. The results of the strength analysis (Fig. 10) show that the stresses were substantially reduced, but they are still much greater than the tensile strength, so this variant would still break during the static test. The concentration of stress is still the most problematic area in connection with the ribs and the inner cylinder.

Sl. 9. *Varianta 1*
Fig. 9. *Variant 1*

Sl. 10. *Največja primerjalna napetost*
Fig. 10. *Maximum equivalent stress*

V naslednji varianti sta bili rebrom iz prve variante simetrično dodani še dve, tako da eno od teh reber leži na robu podpornega kvadra (sl. 11). S tem se bistveno zmanjša površinski pritisk na robu kvadra. Rezultati analize (sl. 12) so pokazali, da so sedaj napetosti že blizu dovoljenim, zanimivo pa je tudi to, da največja napetost ni več na srednjem rebru, ampak na obeh rebrih ob njem.

In the next variant, two new ribs were symmetrically added to the existing ribs, so that one of these ribs lies on the edge of the steel block (Fig. 11). This significantly reduces the surface pressure near the edge of the block. The results of this analysis have shown that the stress is now near to the permitted stress. It is interesting that the maximum stress is no longer in the middle rib, but on the ribs beside it.

Sl. 11. *Varianta 2*
Fig. 11. *Variant 2*

Sl. 12. *Največja primerjalna napetost*
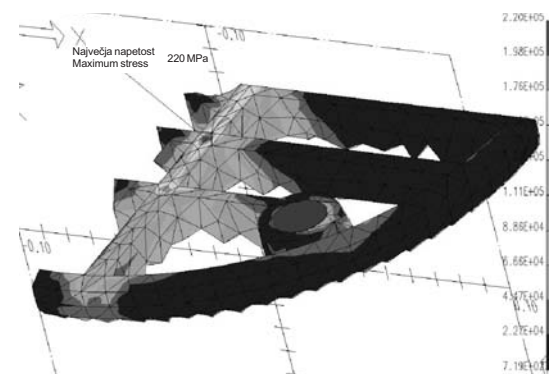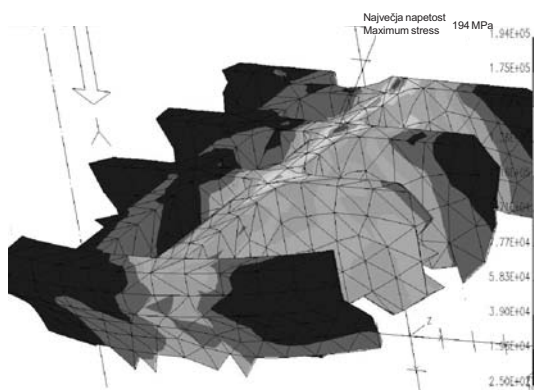Fig. 12. *Maximum equivalent stress*

V tretji varianti so se zgolj dodale zaokrožitve s polmerom 5 mm na mesta, kjer se križajo rebra (sl. 13). Rezultati trdnostne analize so pokazali, da so se napetosti na previsnem robu zmanjšale, vendar še niso manjše od natezne trdnosti. Pokazalo se je tudi, da so napetosti na mestu, kjer je matica vstavljena v bat, sedaj večje od tistih na previsnem robu (sl. 14 in 15).

In the third variant, rounds with a radius of 5 mm were added to the rib joints (Fig. 13). The strength analysis results (Fig. 14 and Fig. 15) showed that the stress was reduced near the edge of the block, although it is still greater than the permitted stress. It was also shown that the stresses near the nut are now greater than the stresses near the edge of the block.

Sl. 13. *Varianta 3*
Fig. 13. *Variant 3*

Sl. 14. *Največja primerjalna napetost na dotiku*
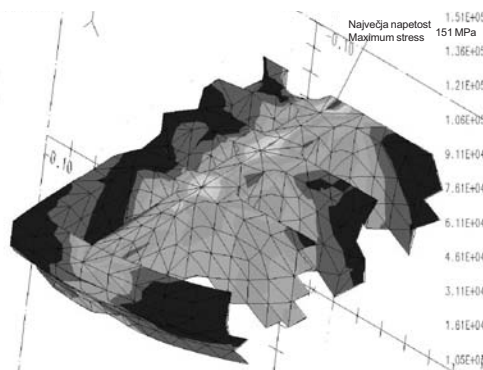Fig. 14. *Maximum equivalent stress in the contact*
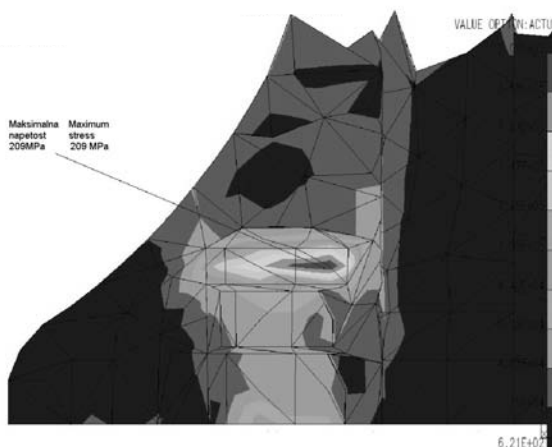
Sl. 15. *Največja primerjalna napetost*
Fig. 15. *Maximum equivalent stress*

V četrti varianti (sl. 16) so bila vsa rebra nekoliko debelejša kakor v tretji varianti, medtem ko se matica vijaka ni spreminjala. Rezultati trdnostne analize (sl. 17 in 18) so pokazali, da so napetosti na previsnem robu manjše od natezne trdnosti, medtem ko so napetosti ob matici vijaka še vedno prevelike.

In the fourth variant, all the ribs were slightly thicker than in the third, while the nut was not changed. The results of the stress analysis showed that the stresses on the edge were now lower than the tensile strength while the stresses near the nut were still too high.

Sl. 16. *Varianta 4*
Fig. 16. *Variant 4*

Sl. 17. *Največja napetost v dotiku*
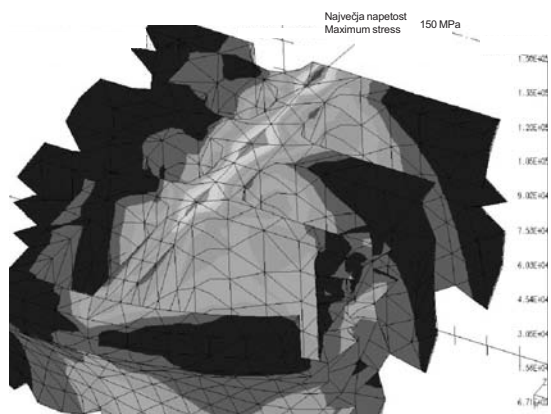Fig. 17. *Maximum equivalent stress in the contact*
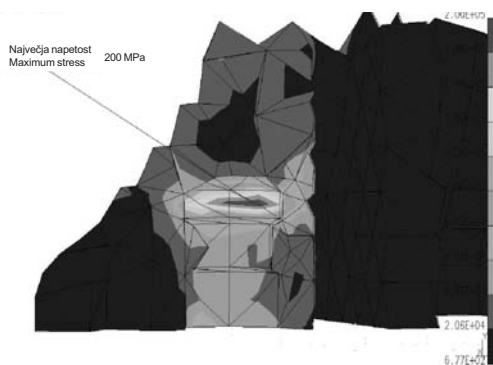
Sl. 18. *Največja napetost ob matici*
Fig. 18. *Maximum equivalent stress*

V peti varianti (sl. 19) se je znižala debelina matice vijaka zato, da je prišlo več materiala nad njo, poleg tega pa se je bat odebelil tudi ob straneh matice. V modelu končnih elementov so se med dotikalnima površinama zopet uporabili elementi špranje, da ne bi bilo nobenih dvomov o pravilnosti rezultata. Iz rezultatov (sl. 20, 21) je razvidno, da so napetosti v tej varianti povsod manjše od natezne trdnosti, tako da bi ta varianta zdržala obremenitve, ki jih zahtevajo evropski tehnični standardi.

In the fifth variant, the thickness of the nut was lowered so that more plastic material was above it. In the finite-element model we used gap elements in order to avoid possible errors in the calculation. From the results (Fig. 20 and Fig. 21) it is clear that all the stresses in this variant are less than the tensile stress, which means that this variant would withstand the loads that are anticipated by European Engineering Standards.

Sl. 19. *Varianta 5*
Fig. 19. *Variant 5*

Sl. 20. *Največja primerjalna napetost v dotiku*
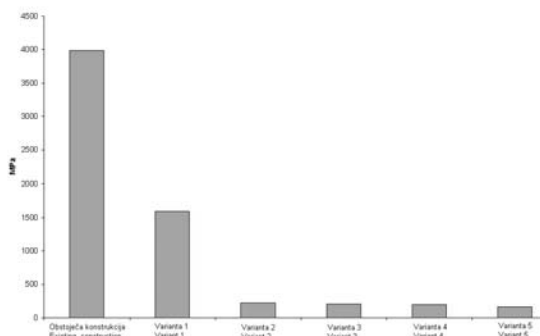Fig. 20. *Maximum equivalent stress in the contact*
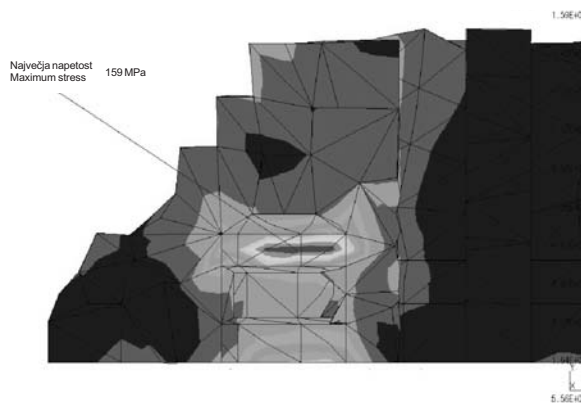
Sl. 21. *Največja primerjalna napetost*
Fig. 21. *Maximum equivalent stress*

3 SKLEP

Če primerjamo mase in napetosti različnih variant odvaljnih batov (sl. 22 in 23), vidimo, da proti sedanjemu izdelku napetosti bistveno bolj padejo, kakor pa se poveča masa pri izboljšanih variantah, zato lahko rečemo, da zmanjšanje napetosti ni toliko posledica dodajanja materiala, kakor je posledica prilagoditve konstrukcije načinu vpetja. Analize so pokazale, da je mogoče izdelati odvaljni bat, ki bo prenesel obremenitve, kakršne terja statični preskus po evropski tehnični standardi, vendar bi tako oblikovan bat prenesel obremenitve samo, če je vpet natančno tako kakor načrtuje standard. Če bi bil rob podstavka postavljen drugje kakor pod rebrom bata, ta skoraj gotovo ne bi prenesel zahtevane obremenitve. Ker imajo nekateri izdelovalci podvozja nekoliko drugačna vpetja, ta bat zanje ne bi bil primeren. Druga težava je v tem, da mora biti bat pri montaži pravilno usmerjen, torej da rebro, za katero je načrtovano, da leži na previsnem robu, dejansko leži tam in ne pravokotno na rob.
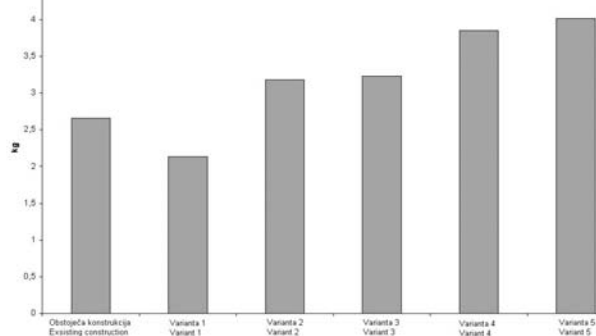
3 CONCLUSION

If we compare the masses and stresses of different variants of air-spring pistons (Fig. 22 and Fig. 23), we see that the stresses drop much more than the mass is increased, which is why we can say that the reduction in the stresses is not the consequence of adding the material as much as it is the consequence of an adjustment of the design to the suspension. Our analyses showed that it is possible to produce a plastic air-spring piston that would withstand the loads that are anticipated by European Engineering Standards, but such a piston would withstand all the loads only if it were supported exactly as it is predicted in the standard. If the edge were to be placed anywhere else, for example, under the rib of the piston, this piston would almost certainly not withstand the required loads. Because some manufacturers have slightly different supports this piston would not be appropriate for them. The other problem is that during assembly the piston should be adequately oriented, so that the rib that is supposed to be on the edge of the block is really there and not perpendicular to it.


Sl. 22. *Primerjava največjih napetosti*
Fig. 22. *Comparison of maximum stresses*

Sl. 23. *Primerjava teže*
Fig. 23. *Comparison of weights*

Analiza za primer vpetja po vsej spodnji površini za varianto 5 ni bila narejena. Ker je takšno vpetje bistveno bolj ugodno, bi peta varianta zanesljivo zdržala statični preskus tudi za tak način vpetja, vendar se pojavlja vprašanje, ali je primerno uporabljati peto varianto odvaljnega bata za vpetje po celotni spodnji površini bata, ker je težja od sedanjega izdelka in s tem tudi dražja. Po drugi strani je zopet vprašanje, ali je primerno izdelovati za različne izdelovalce podvozij različne odvaljne bate. Rešitev problema je, da se pod celotno spodnjo površino sedanjega odvaljnega bata postavi jeklena plošča (sl. 24), ki omili zgostitve napetosti ob previsnem robu. Tudi ta varianta ni idealna, saj smo dobili nov element v sestavi zračne vzmeti, vendar se je v praksi izkazala kot najcenejša rešitev. Analize takšnega načina vpetja niso bile narejene, ker je bilo bolj preprosto narediti preskus, ki ga je bat uspešno prestal. Z računalniki, ki so bili na voljo, bi ta način vpetja zelo težko trdnostno analizirali, saj je računanje že sedaj trajalo nekaj ur, če pa bi v model končnih

An analysis of the fifth variant for support on the whole lower surface of the piston was not made. Since such a support is much more favourable, the fifth variant would certainly withstand all the loads of the static test for that kind of support. However, there is a question: is it reasonable to use the fifth variant of the piston for the suspension on the whole lower surface, because this variant is heavier, and thus more expensive than the current product? A possible solution to this problem is to put a steel plate under the lower surface of the existing piston (Fig. 24). This plate would diminish the stress concentration near the edge of the block. This is also not an ideal solution, but it has been shown in practice that it is the cheapest solution so far. An analysis of such a support was not made because it was simpler to make a test, which the piston passed. To solve this problem with finite-element analysis would be very difficult, because computing time, which was several hours, would have had to be prolonged if we were to

elementov dodali še eno dodatno ploščo pod valjem, bi s tem dobili še nekaj dodatnih elementov in še eno dodatno dotikalno površino, na kateri bi morali uporabiti elemente špranje. To bi vse skupaj bistveno podaljšalo čas računanja. Ker pa razvoj računalnikov zelo hitro napreduje, se bodo podobne analize v praksi vse bolj uveljavljale.

add the additional plate to the model because it would not only increase the number of elements, but it would also mean a new contact surface with gap elements. Since development in the computer industry is very rapid, this type of analysis will become increasingly common.
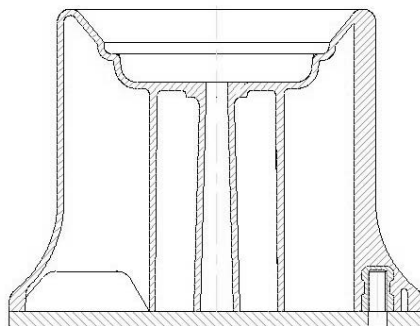
Sl. 24. *Drugačna rešitev*
Fig. 24. *Alternative solution*

4 LITERATURA
4 REFERENCES

[1] (1998) Catalog 1998, *General Electric*
[2] Spyrakos, C., Finite element modeling, *West Virginia University Press*
[3] Lawry, M.H., I – deas Master Series student guide, *Structural Dynamics Research Corporation*
[4] Zienkiewicz, O.C. (1991) The finite element method, *Mc Graw-Hill Publishing Company*, London.
[5] Oberg, E., Jones, F.D., Horton, H.L., Ryffel, H.H. (1996) Machinery's handbook, *Industrial Press Inc.*, New York.
[6] Göbel, E. F. (1974) Rubber springs design, London.
[7] (1985) Procédure de réception de ressort à air, *European Engineering Standards 810*.

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