

## SANACIJA I REKONSTRUKCIJA AUTOKLAVA OVERHAUL AND RECONSTRUCTION OF AN AUTOCLAVE

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### Ključne reči

- napon
- deformacija
- rekonstrukcija
- sanacija
- autoklav

### Izvod

Izveden je projekt sanacije i rekonstrukcije autoklava, bitnog dela opreme za sušenje uglja, po zahtevu kompanije Kolubara Prerada-Vreoci. Autoklavi rade pod pritiskom na povišenoj temperaturi. U toku eksploatacije na njima je dolazilo do čestih proboja plašta u zoni držača segmenata. Na osnovu analize metodom konačnih elemenata predloženo je i izvedeno novo rešenje. Uzrok pojave proboja je otklonjen i autoklavi se sada koriste sa uspehom.

### UVOD

Autoklav je u postrojenju za sušenje uglja osnovna komponenta, posuda koja radi pod pritiskom izložena povišenoj temperaturi. U toku eksploatacije postrojenja u kompaniji Kolubara prerada, Vreoci, u koje je ugrađeno 16 autoklava, često je dolazilo do nastanka prslina i njihovog razvoja po debljini zida sve do procurivanja fluida kroz plašt u zoni držača segmenata. Po zahtevu kompanije izveden je projekt sanacije i rekonstrukcije autoklava.

Projekat sanacije i rekonstrukcije autoklava u zoni nosača uređaja za pražnjenje je obuhvatio sledeće operacije:

- utvrđivanje uzroka pojave prslina, taloženja uglja i habanja materijala u zoni držača segmenta uređaja,
- predlog sanacije,
- rekonstrukciju autoklava radi sprečavanja pojave prslina i stanjenja zida posude autoklava u zoni držača segmenta uređaja.

Osnovna konstrukcija posude autoklava i glavni podsklopovi su prikazani na sl. 1.

### UTVRĐIVANJE UZROKA OTKAZA

Na sl. 2 je prikazan detalj jednog oslonca dva susedna segmenta uređaja za pražnjenje. Rešenje je nepovoljno, jer su obe ploče držača segmenta zavarene za omotač autoklava samo sa spoljnje strane, bez provara (detalj Z).

### Keywords

- stress
- deformation
- redesign
- overhaul
- autoclave

### Abstract

The project of overhaul and redesign of autoclaves, a substantial part of coal drying equipment is realised at the requirement of Kolubara Prerada-Vreoci. Autoclaves operate under pressure at elevated temperature. Frequent in-service leakages occur on their shells in the segment support zone. Based on finite element method analysis, a new solution is offered and applied. The cause of leakage is eliminated and autoclaves are now in use with success.

### INTRODUCTION

The autoclave in the coal drying equipment is a substantial component, operating as a pressure vessel exposed to elevated temperature. During exploitation of equipment in the company Kolubara prerada, Vreoci, where 16 autoclaves are used, cracks initiated frequently and developed through wall thickness up to the leakage of fluid from the mantle in the segment support zone. Based on company requirement an overhaul and redesign project is made.

Autoclave overhaul and redesign project in the support zone of emptying device included following operations:

- establishing the cause of crack initiation, coal deposition and material wear in zone of device segments support,
- overhaul proposal,
- autoclave redesign in order to prevent crack occurrence and wall thinning of autoclave vessel in the support zone of device segments.

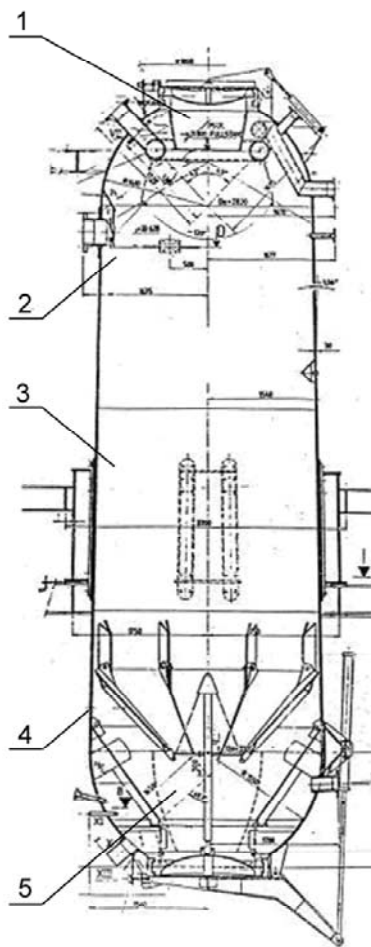
The general design of autoclave vessel and principal substructures are presented in Fig. 1.

### CAUSE OF FAILURE DETERMINATION

Figure 2 shows a detail of a support of two neighbouring segments of the emptying device. The solution is inconvenient, since both segment support plates are welded only on outside to autoclave shell, with no penetration (detail Z).

## Glavni podsklopovi autoklava

1. Gornje sferno dance, priključci i uređaj za otvaranje gornjeg poklopca posude
2. Gornji konusni omotač iznad oslanjanja
3. Srednji konusni omotač i oslanjanje
4. Donji konusni omotač, zona nosača uređaja za pražnjenje, segmenti uređaja, graničnici i ploče za ceđenje
5. Donje sferno dance, priključci, uređaj za otvaranje donjeg poklopca posude



## Major sub-structures of an autoclave

1. Top spherical lid, connectors and device for opening of vessel top lid
2. Top cone shell above the support
3. Middle cone shell and support
4. Bottom cone shell, zone of emptying device, device segments, limitators and draining boards
5. Spherical bottom lid, connectors, device for opening the bottom vessel lid

Slika 1. Osnovna konstrukcija posude autoklava  
Figure 1. The general design of the autoclave vessel.

Prethodna analiza je pokazala da je:

- geometrija držača segmenta omogućila nagomilavanje uglja u zoni držača do njegovog potpunog zapušenja;
- nagomilavanje uglja izazvalo habanje materijala u ovoj zoni, zbog kretanja čestica uglja pri nagomilavanju;
- pojava prslina posledica uspostavljene visoke vrednosti napona zbog uticaja koncentracije napona, zapušenih držača, neprovarenog korena šava držača i smanjene debljine omotača u zoni držača segmenta.

Izgled nekih otkrivenih prslina je prikazan na sl. 3, a izgled proboja se vidi na sl. 4.

## PRORAČUN KONSTRUKCIJE AUTOKLAVA

Modeliranje konstrukcije autoklava izvedeno je primenom konačnih elemenata za tanke ploče, a za modeliranje oslonaca su primenjeni zapreminski konačni elementi.

Deformacije i naponi konstrukcije autoklava su proračunati numerički, primenom metode konačnih elemenata i programa KOMIPS, /1, 2, 3/. U proračunu je dužina izražena u cm, sila u kN, a napon u  $\text{kN/cm}^2$ .

Na sl. 5 prikazana je geometrija numeričkog modela konstrukcije autoklava, koji je razmatran kao specifična posuda pod pritiskom, /4, 5/. Proračun je izveden za pritisak  $0,3 \text{ kN/cm}^2$  i temperaturu  $200^\circ\text{C}$ .

Provisional analysis has shown that:

- the geometry of the segment support enabled accumulation of coal in the support zone until complete blockage;
- accumulation of coal produced wearing of material in this support zone due to coal particle movement;
- cracks initiated due to high stress values, caused by stress concentration effect, support blockage, non penetrating root of welded support and reduction of shell thickness in the segment support zone.

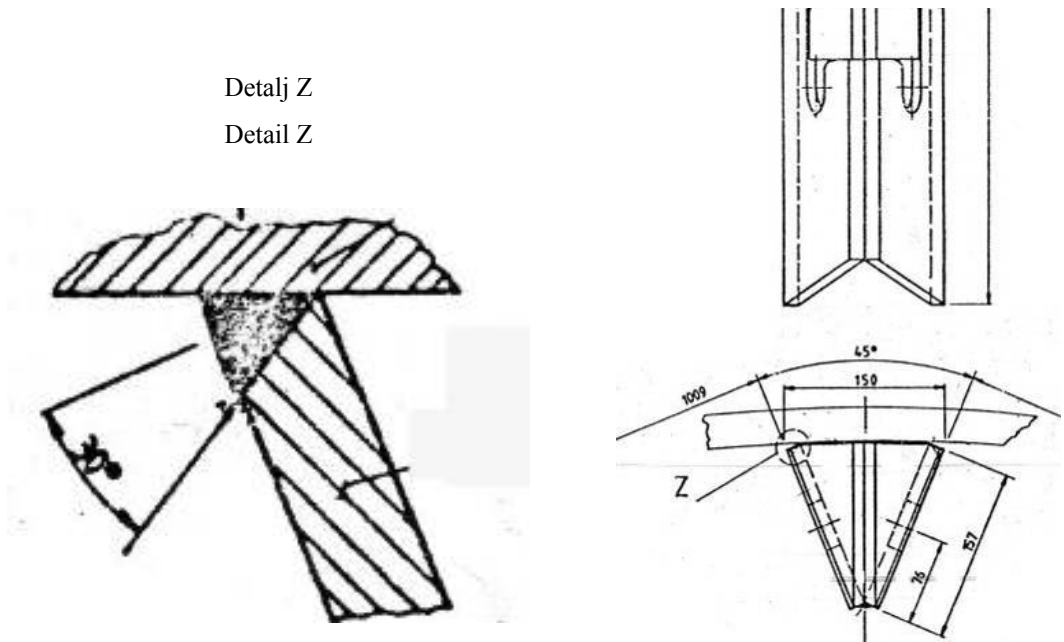
The view of some detected cracks is presented in Fig. 3, and the view of leakage is shown in Fig. 4.

## CALCULATION OF AUTOCLAVE CONSTRUCTION

Modelling of the autoclave construction was performed using thin plate finite elements, while supports were modelled using volume finite elements.

Deformations and stresses of the autoclave are calculated numerically using finite element method and KOMIPS programme, /1, 2, 3/. In the calculation, length is expressed in cm, force in kN, and stress in  $\text{kN/cm}^2$ .

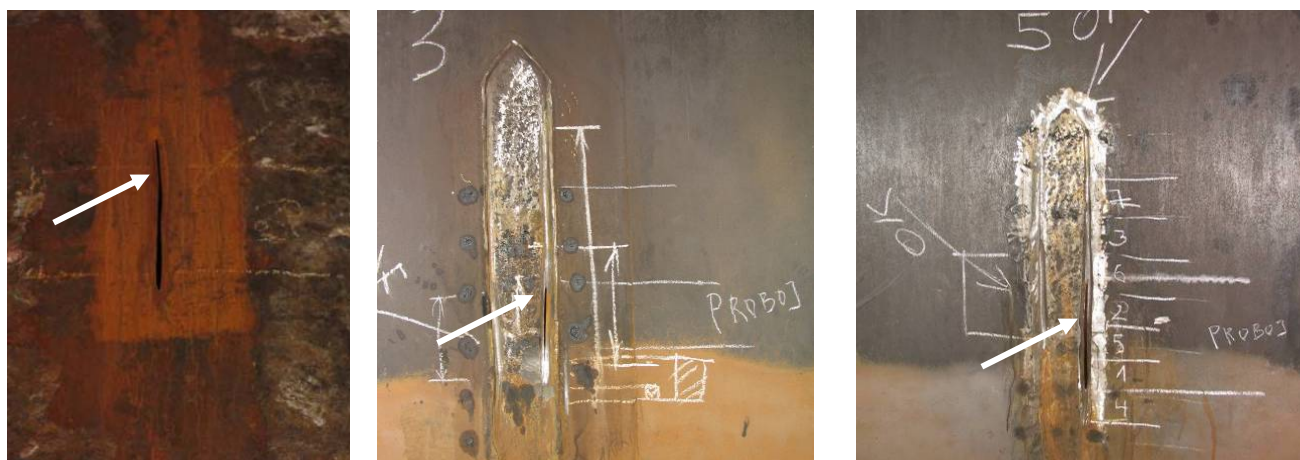
Figure 5 presents the geometry of the numerical model of autoclave construction, considered as a specific pressure vessel, /4, 5/. Calculation is performed for the pressure of  $0.3 \text{ kN/cm}^2$  and temperature  $200^\circ\text{C}$ .



Slika 2. Detalj nosača uređaja za pražnjenje  
 Figure 2. Detail of a support of two neighbouring segments of the emptying device.

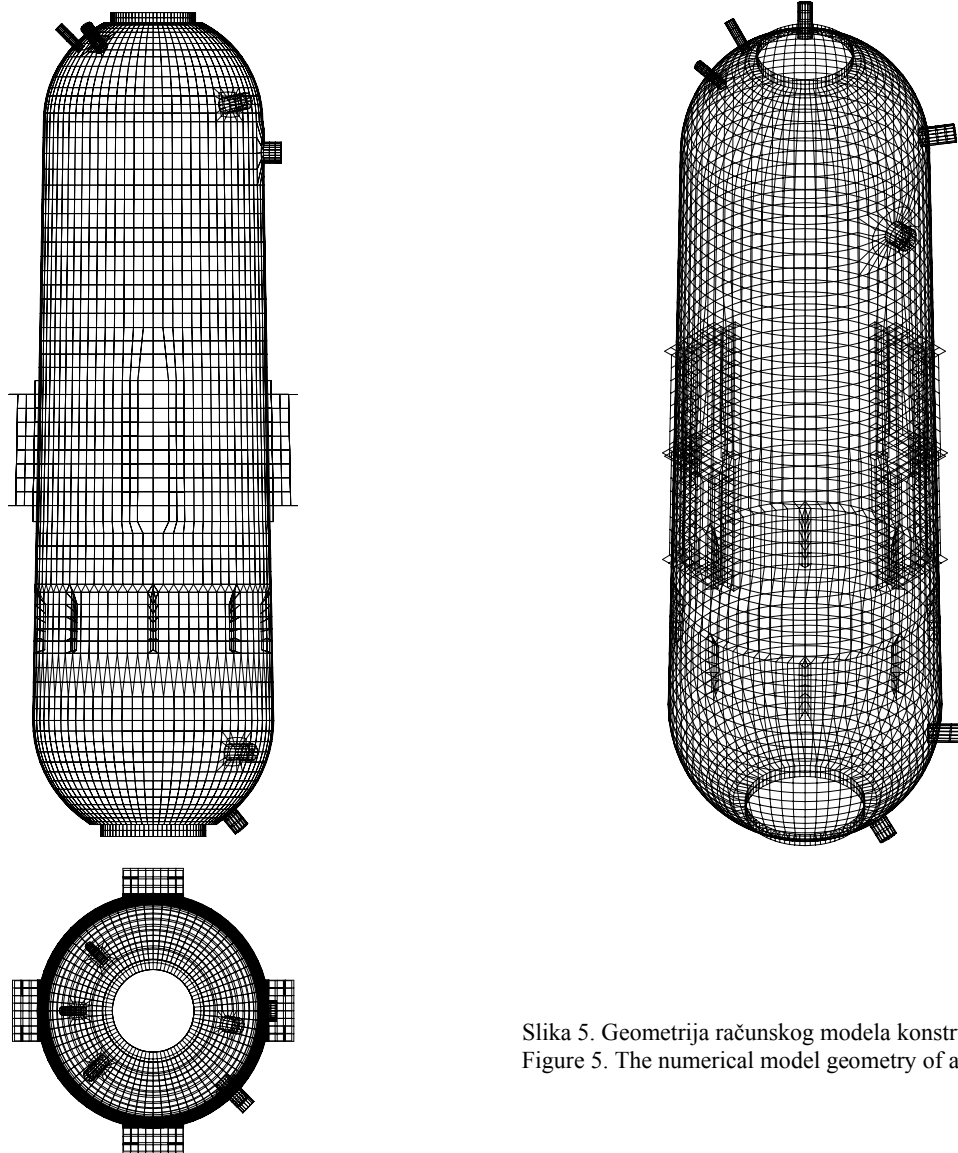


Slika 3. Otkrivene prsline (strelice)  
 Figure 3. Detected cracks (arrows).



Slika 4. Izgled proboja prolazne prsline  
 Figure 4. A view of leakage crack.

Postojeća konstrukcija autoklava razmatrana je u dva slučaja: bez zapušenja i sa zapušenjem u zoni oslanjanja dva susedna segmenta uređaja. Rezultati proračuna bez zapušenja ukazuju na stanje deformacije i napona u regularnim uslovima eksploatacije. Kada se prostor između dve kose ploče zapuši pritisak fluida deluje samo sa jedne strane ploče, pa rezultati proračuna ukazuju na to – postoje li uslovi za pojavu prsline na omotaču posude u toj zoni.



Slika 5. Geometrija računskog modela konstrukcije autoklava  
Figure 5. The numerical model geometry of autoclave design.

Rezultati proračuna modela postojeće konstrukcije autoklava za oba razmatrana slučaja (bez i sa zapušenjem) dati su na sl. 6, 7, 8 i 9.

Proračun postojećeg autoklava kada nema zapušenja je pokazao:

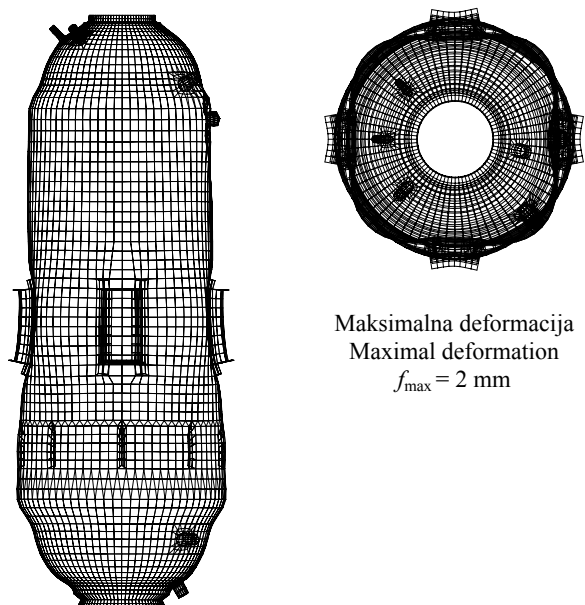
- da položaj oslonca autoklava izuzetno nepovoljno utiče na deformaciju i napon konstrukcije autoklava;
- da je maksimalni napon od  $14,6 \text{ kN/cm}^2$  pri radnom pritisku od 30 bar je prihvatljiv;
- da je izražena koncentracija napona oko oslonaca autoklava, držača segmenata i oko priključaka, pa je tu vrednost napona znatno veća, ali se ne može se tačno odrediti.

The existing autoclave design was examined for two cases: with no blockage and with a blockage in the support zone of two neighbouring device segments. Calculation results with no blockage indicate the strain and stress state in regular service condition. When the area between two slant plates is blocked, fluid pressure acts only from one side, and calculation results can indicate whether conditions for crack initiation in this zone of vessel mantle are present.

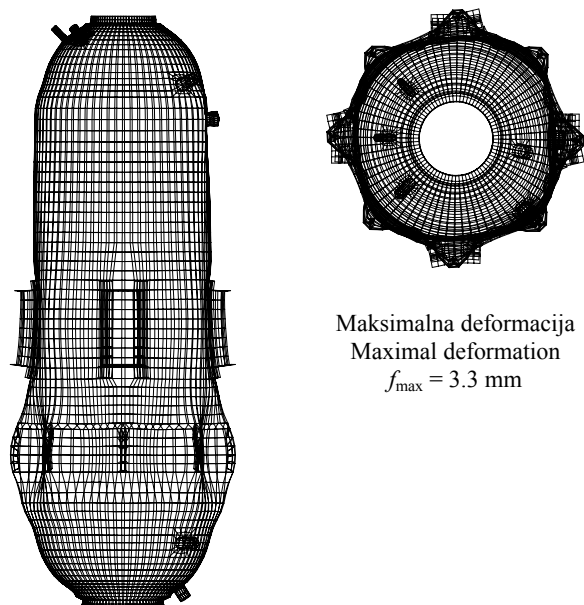
Results of calculation of the existing autoclave construction model in both examined cases (with and without blockage) are given in Figs. 6, 7, 8, and 9.

The calculation of existing autoclave in the case of no blockage shows:

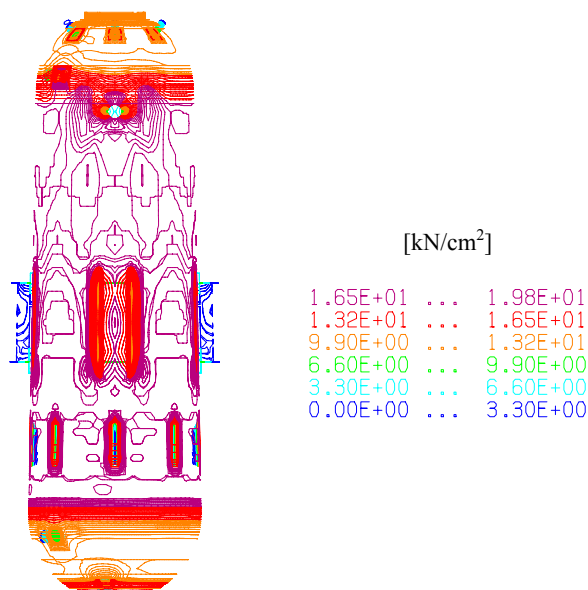
- the position of autoclave supports very unfavourably affect the strains and stresses of the autoclave design;
- the maximal stress of  $14.6 \text{ kN/cm}^2$  at operating pressure of 30 bar is acceptable;
- stress concentration is expressed around the autoclave rests, segment supports, and around connectors with higher stress values, but cannot be determined accurately.



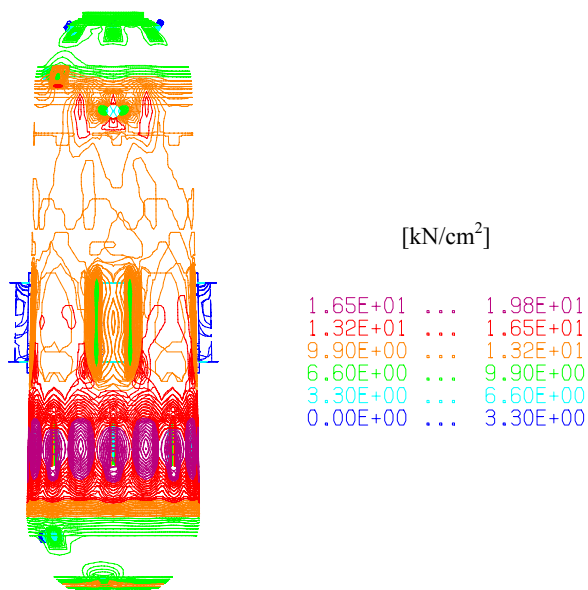
Slika 6. Deformacija postojeće konstrukcije autoklava bez zapušnja  
Figure 6. Strains of an autoclave with no blockage.



Slika 7. Deformacija postojeće konstrukcije autoklava sa zapušnjem  
Figure 7. Strains of an autoclave with a blockage.



Slika 8. Ekvivalentni napon konstrukcije autoklava bez zapušnja  
Figure 8. Equivalent stress of an autoclave with no blockage.



Slika 9. Ekvivalentni napon konstrukcije autoklava sa zapušnjem  
Figure 9. Equivalent stress of an autoclave with a blockage.

Zaključak proračuna postojećeg autoklava za slučaj da je zapušten unutar držača segmenta glasi:

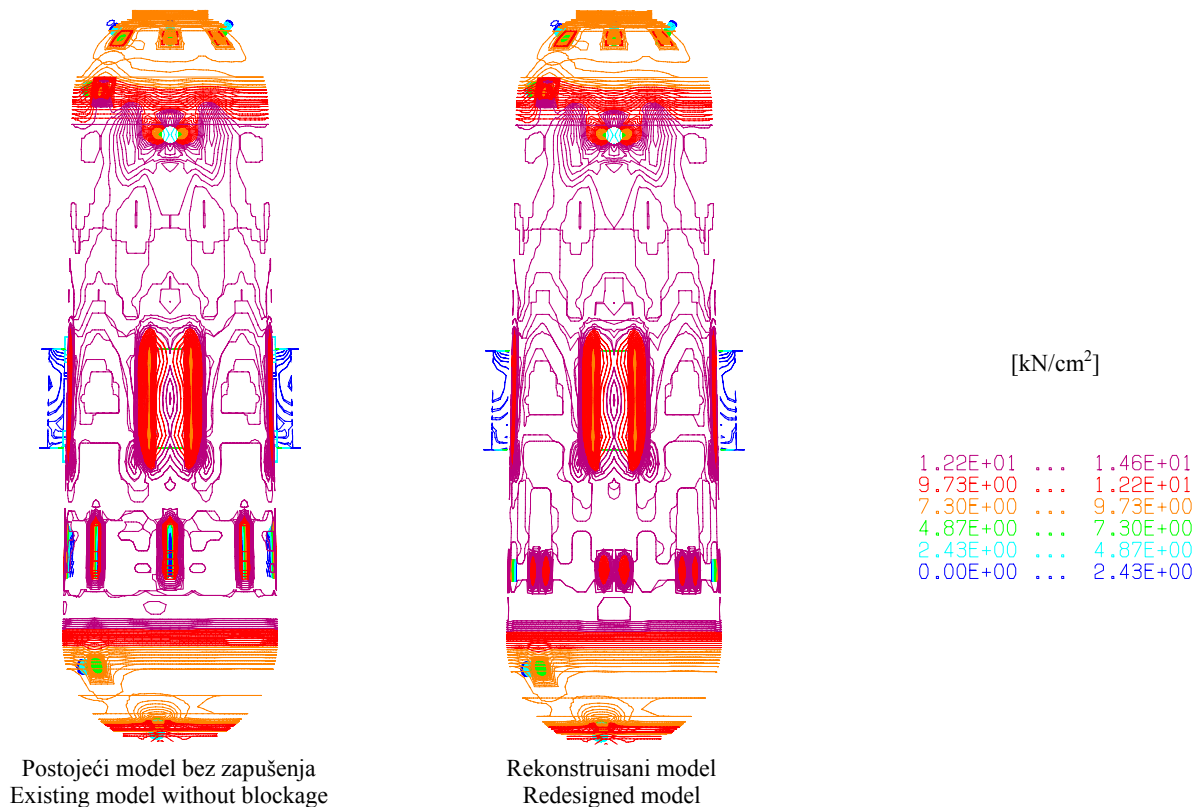
- deformacija posude u zoni držača segmenta značajno se povećala i dobila nepovoljan oblik;
- maksimalni napona je povećan na 19,8 kN/cm<sup>2</sup>,
- maksimalna vrednost napona je prisutna u celoj zoni omotača autoklava oko držača segmenta;
- koncentracija napona je još više izražena i zahvatila je potpuno omotač autoklava oko držača segmenta.

Radi poređenja i analize, rezultati proračuna naponskog stanja rekonstruisanog autoklava su dati na sl. 10 i 11.

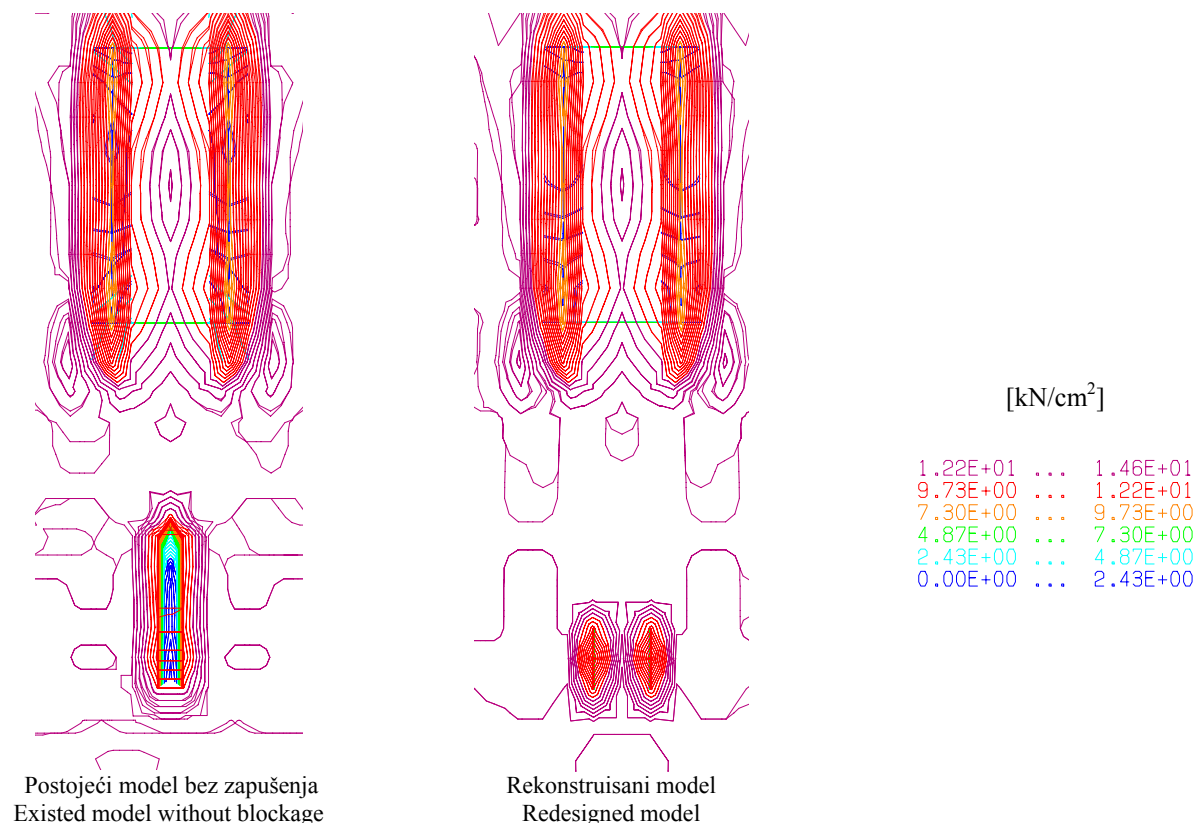
The conclusion of the calculation of existing autoclave in the case when it is blocked in the segment support reads:

- deformation in vessel segment support zone has increased significantly and its shape is unfavourable;
- the maximal stress value is increased to 19.8 kN/cm<sup>2</sup>;
- the maximal stress value is present in the whole autoclave shell zone around the segment support;
- stress concentration is more expressed and it has included the complete autoclave shell around the segment support.

For sake of comparison and analysis, stress-strain calculation results of redesigned autoclave are shown in Figs. 10 and 11.



Slika 10. Ekvivalentni napon (kN/cm<sup>2</sup>)  
Figure 10. Equivalent stress (kN/cm<sup>2</sup>).



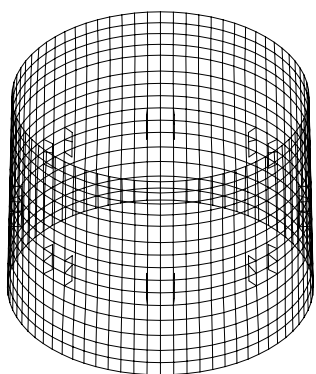
Slika 11. Naponsko polje postojeće i rekonstruisane konstrukcije autoklava u zoni oslanjanja – ekvivalentni napon  
Figure 11. Stress field of existing and redesigned autoclave construction in the supporting zone – equivalent stress.

## IDEJNO REŠENJE SANACIJE

Idejno rešenje rekonstrukcije autoklava obuhvata:

- uklanjanje svih postojećih držača segmenata uređaja za pražnjenje;
- navarivanje omotača autoklava u zoni držača segmenata da se dobije kontinualna površina omotača debljine zida ne manje od 27 mm (tehnologija zavarivanja STZ-1);
- razdvajanje ploča držača, tako da se izbegne oslanjanje dva susedna segmenta na jednom mestu i da se spreči formiranje naslaga uglja koje dovode do zaluženja i habanja materijala;
- ploče držača treba zavariti u neoštećenoj zoni koja se nalazi na oko 125 mm od ispitivanog šava, odnosno, ploče treba udaljiti od ose za 190 mm.

Geometrija modela konačnih elemenata idejnog rešenja oslanjanja nosača uređaja za pražnjenje je data na sl. 12.



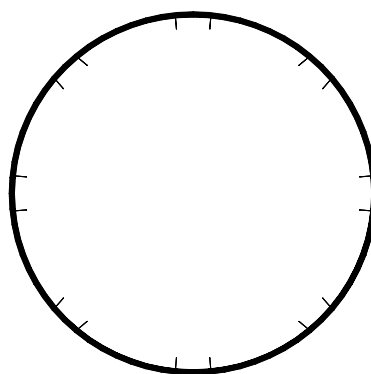
Slika 12. Donji konusni omotač i rekonstruisano oslanjanje segmenata uređaja za pražnjenje  
Figure 12. Bottom cone shell and reconstructed supports of the emptying device segments.

## CONCEPTUAL OVERHAUL SOLUTION

Conceptual redesign autoclave solution includes:

- removal of all existing segment supports of the emptying device;
- surfacing of autoclave shell in the segment support zone to achieve continual shell surface of wall thickness not less than 27 mm (the STZ-1 welding technology);
- the separation of support plates to avoid supporting two neighbouring segments in one spot and eliminate formation of coal deposits leading to blockage and wear of material;
- plates need to be welded inside the undamaged zone, around 125 mm from the investigated welded joint, e.g. the plates must be separated 190 mm from the axis.

The geometry of the finite element model of conceptual design of emptying device support is given in Fig. 12.



## ANALIZA IDEJNOG REŠENJA

Rezultati proračuna polja napona rekonstruisanog autoklava na sl. 10 i 11 upoređeni sa rezultatima proračuna postojeće konstrukcije autoklava bez zaluženja držača segmenta, da bi se utvrdila prednost predložene rekonstrukcije u odnosu na ranije rešenje. Na sl. 11 uvećana je zona oslanjanja, jer je u tom području došla u najvećoj meri do izražaja promena napona.

Zaključak proračuna je da rekonstrukcija držača segmenata uređaja za pražnjenje ni u kom pogledu nije pogoršala deformacijsko i naponsko polje konstrukcije autoklava.

## TEHNIČKA DOKUMENTACIJA I IZVOĐENJE

Osnovi zadatak projekta je bio da se analiziraju uzroci čestih otkaza autoklava. Prošireni zadatak projekta je da se prikladnom rekonstrukcijom obezbedi pouzdana eksploatacija postrojenja za sušenja uglja, što je podrazumevalo i razradu konstrukcijskog rešenja do nivoa proizvodne dokumentacije. Rešenje problema je zahtevalo rekonstrukciju držača. Ilustracije radi, na sl. 13 i 14 su prikazani crteži nekih rekonstruisanih važnih delova.

Zavod za zavarivanje iz Beograda je izveo rekonstrukciju prema sopstvenom izvođačkom projektu sanacije, uključujući specifikaciju postupka zavarivanja (WPS). Izgled izvedenog zavarenog spoja držača, prikazan je na sl. 15.

## ANALYSIS OF CONCEPTUAL SOLUTION

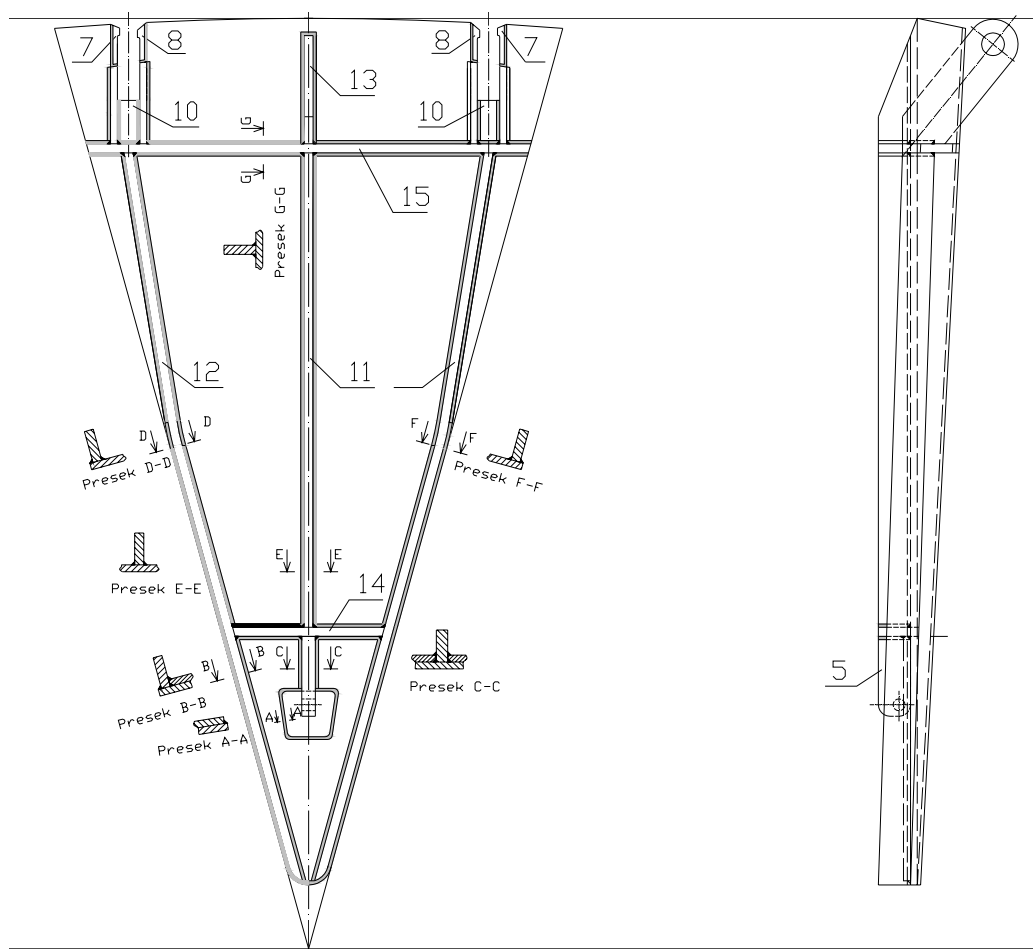
The results of stress field calculation of the redesigned autoclave in Figs. 10 and 11 are compared with calculation results of existing autoclave design without blockage of segment supports, so in order to establish the benefit of proposed redesign in regards to the previous solution. In Fig. 11 the support zone is magnified, since in this region the stress change is mostly expressed.

The conclusion of the calculation is that redesign of the segment support of emptying device did not worsen in any sense the strain and stress field of the autoclave structure.

## TECHNICAL DOCUMENTATION AND PERFORMANCE

The basic task of the project was to analyse causes of autoclave frequent failures. Extended task was to assure reliable service of equipment for coal drying by proper redesign, comprising the development of design solution to the level of manufacturing documentation. The solution requested for support redesign. As an illustration, drawings of some redesigned important parts are presented in Figs. 13 and 14.

The Welding Institute from Belgrade was the contractor for the overhaul, based on its own manufacturing project, including welding procedure specification (WPS). The illustration of performed welded joint of the support is presented in Fig. 15.



Slika 13. Držač  
Figure 13. Support.

#### AKTIVNOSTI POTREBNE ZA PROCENU PREOSTALOG VEKA AUTOKLAVA

Predloženo tehničko unapređenje koje zahteva sanaciju i rekonstrukciju držača segmenta i segmenta uređaja za pražnjenje predviđa produženje pouzdane eksploatacije autoklava u rekonstruisanoj zoni za duži vremenski period.

Da bi sa sigurnošću predvideli pouzdanu eksploataciju rekonstruisanog autoklava predlaže se izrada elaborata procene preostalog veka autoklava. To je u osnovi eksperimentalno-numerička procedura koja se mora prilagoditi razmatranoj konstrukciji.

Eksperimentalno-numerička procedura obuhvata sledeće elemente:

- izbor jednog autoklava kao predstavnika za procenu preostalog radnog veka;
- vizuelni pregled cele konstrukcije autoklava;
- ispitivanje svih zavarenih spojeva;
- merenje debljina svih ploča konstrukcije autoklava;
- određivanje parametara mehanike loma ispitivanjem odgovarajućih epruveta;
- eksperimentalno dinamičko merenje deformacija i temperature u eksploataciji;
- prikladnu proceduru proračuna za procenu preostalog veka na osnovu izvedenog proračuna čvrstoće autoklava i navedenih eksperimentalnih ispitivanja.

#### ACTIVITIES NECESSARY FOR AUTOCLAVE REMAINING LIFE ASSESSMENT

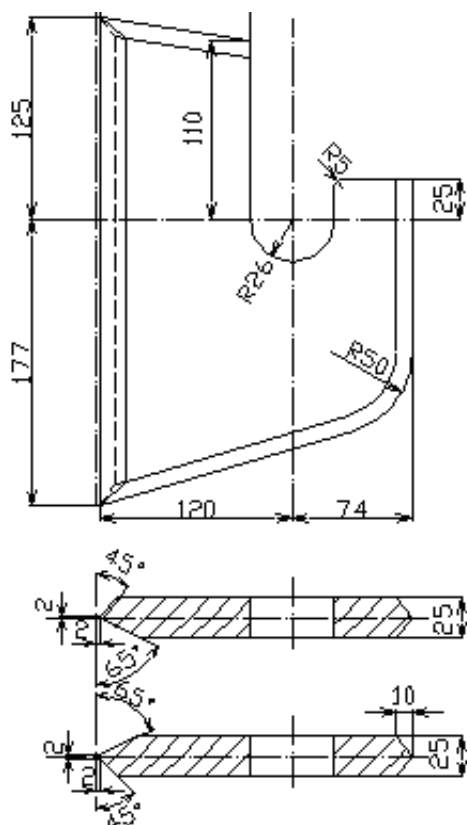
The proposed technical improvement requiring overhaul and redesign of segment supports and segments of emptying device includes the extension of reliable autoclave service in the redesigned zone for a longer period.

In order to predict with certainty the reliable service of the redesigned autoclave it is proposed to elaborate a report for remaining autoclave life assessment. This is in fact an experimental and computational procedure that must be adapted to the considered construction.

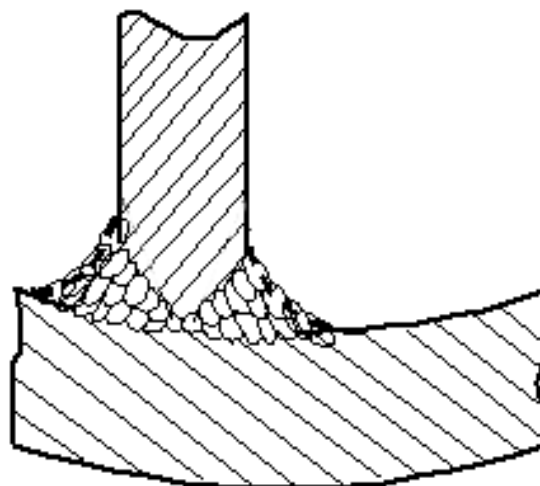
The experimental and numerical procedure includes the following elements:

- selection of one autoclave as representative for the assessment of remaining operating life;
- visual inspection of the complete autoclave construction;
- testing of all welded joints;
- measuring thickness of all plates in autoclave construction;
- determination of fracture mechanics parameters by testing corresponding specimens;
- experimental dynamic measurement of strains and temperature in service;
- convenient calculating procedure for assessment of remaining operating life based on strength calculation of autoclave and performed experimental tests.





Slika 14. Uška  
Figure 14. Lug.



Slika 15. Izgled realizovanog zavarenog spoja  
Figure 15. An illustration of the performed welded joint.

## ZAKLJUČAK

Program KOMIPS, razvijen na bazi konačnih elemenata za analizu stanja napona i deformacija konstrukcije, je već uspešno primenjen u mnogim slučajevima /6–17/. Prikazani primer rekonstrukcije autoklava je još jednom potvrdio da se KOMIPS može sa uspehom primeniti kao pogodan alat ne samo za analizu ponašanja složenih konstrukcija, već i za praktično rešavanje problemima integriteta i pouzdane eksploatacije složenih sistema.

Na osnovu analize izvedene konstrukcije autoklava u zoni uređaja za pražnjenje i utvrđivanjem uzroka nastajanja prslina i njihovog rasta do proboja zida zbog nepovoljne geometrije držača segmenta, visoke koncentracije napona, zapušenosti držača, neprovarenog korena i habanjem smanjene debljine omotača zaključeno je da prvobitno projektno rešenje nije prikladno.

Da bi se utvrđeni razlozi pojave otkaza otklonili i obezbedila produžena pouzdana eksploatacija bila je neophodna rekonstrukcija sistema oslanjanja, razvojem novog idejnog rešenja nosača i segmenta uređaja za pražnjenje.

Novo idejno rešenje nosača uređaja za pražnjenje omogućava ugradnju novih nosača na neoštećenom delu omotača autoklava, sprečava formiranja naslaga uglja, habanje materijala i pojavu prslina u zoni nosača uređaja segmenta za pražnjenje autoklava.

Primenom predloženog rešenja moguće je produžiti vek eksploatacije autoklava u rekonstruisanoj zoni za duži period.

## CONCLUSION

Programme KOMIPS, developed based on finite elements for stress and strain state analysis of structures, has been already applied with success in many cases /6–17/. The presented example of autoclave redesign has confirmed once again that KOMIPS can be successfully used as a convenient tool not only for behavioural analysis of complex structures, but also for practical solutions of integrity and reliable service of complex systems.

Based on analysis of performed autoclave construction in the zone of the emptying device and establishing the causes of crack initiation and their growth until leakage, caused by unsuitable segment support geometry, high stress concentration, support blockage, non penetrating root welds and shell thickness reduced by wearing, it is concluded that the initial design solution is not adequate.

In order to eliminate causes for failure occurrence and assure extended reliable service, a redesign of the support system was necessary, developing a new conceptual design of supports and segments of the emptying device.

The new conceptual design of the support of the emptying device enables implementation of new supports in the undamaged part of the autoclave shell, prevents formation of coal deposits, wear of material and crack initiation in support zone of segments of autoclave emptying.

Applying the proposed solution enables extension of reliable autoclave service in the redesigned zone for an extended period.

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