Miodrag Arsić [1], Vujadin Aleksić [1], Zoran Anđelković [2]

TEORIJSKA I EKSPERIMENTALNA ANALIZA ZAVARENE KONSTRUKCIJE NOSAČA SATELITA PLANETARNOG REDUKTORA

THEORETICAL AND EXPERIMENTAL ANALYSIS OF WELDED STRUCTURE SUPPORTING SATELLITE PLANETARY GEAR

Originalni naučni rad / Original scientific paper
UDK /UDC: 621.879.48.016
Rad primljen / Paper received: 25.5.2007.

Adresa autora / Author's address:
[1] Institut za ispitivanje materijala d.d, Bulevar vojvode Mišića 43, Beograd, Srbija, Miodrag.Arsic@Institutims.co.yu
[2] Delta inženjering, Zaplanjska 86, Beograd, Srbija

Ključne reči
- rotorni bager
- nosač satelita
- spoljnje opterećenje
- zavareni spojevi

Keywords
- bucket wheel excavator
- satellites support
- external load
- welded joints

Izvod

U radu su dati rezultati teorijskih i eksperimentalnih analiza opterećenja, osnovnog materijala, zavarenih spojeva, tehnologije izrade, konstrukcijskog rešenja, kao i prelomnih površina nosača satelita planetarnog reduktora za pogon radnog točka bagera SRs 1300.26/5.0+VR±10. Cilj istraživanja je utvrđivanje uzroka loma nosača satelita, čija je posledica bila velika havariju sklopa reduktora i radnog točka bagera.

Abstract

This paper presents results of theoretical and experimental analyses of loads, parent material, welded joints, manufacturing technology, design solution, and fracture surface of supporting structure of satellite planetary gear used in driving the wheel of bucket excavator type SRs 1300.26/5.0 +VR±10). Research was aimed to establish the cause of fracture of satellite support, followed by catastrophic failure of gear box and working wheel.

UVOD

Postojeći dinamički modeli noseće konstrukcije, mehanizama i pogona rotornih bagera, odnosno modeli spoljnjeg opterećenja izazvanog otporom kopanju, ne omogućavaju sagledavanje njihovog uticaja na dinamičko ponašanje rotornog bagera.

U praksi se često dešavaju prevremena oštećenja kašika rotora, strele rotora, delova reduktora i čitavih konstrukcija rotornih bagera. Ovo se objašnjava neadekvatnom projektom, nedovoljnim podacima o svojstvima osnovnog materijala i njihovim zavarenim spojevima i propustima u tehnologiji izrade delova /1,2,3/.

Analizom otkaza i ispitivanjem oštećenih i polomljenih delova mogu se dobiti podaci za razvoj postupaka projektovanja reduktora, za poboljšanje svojstava materijala i tehnologija i za razvoj novih materijala.

Obim potrebnih i izvedenih teorijskih i eksperimentalnih analiza otkaza i loma komponenti zavarene konstrukcije nosača satelita planetarnog reduktora za pogon radnog točka bagera SRs 1300.26/5.0+VR±10 prikazan je blok dijagramom na sl. 1.

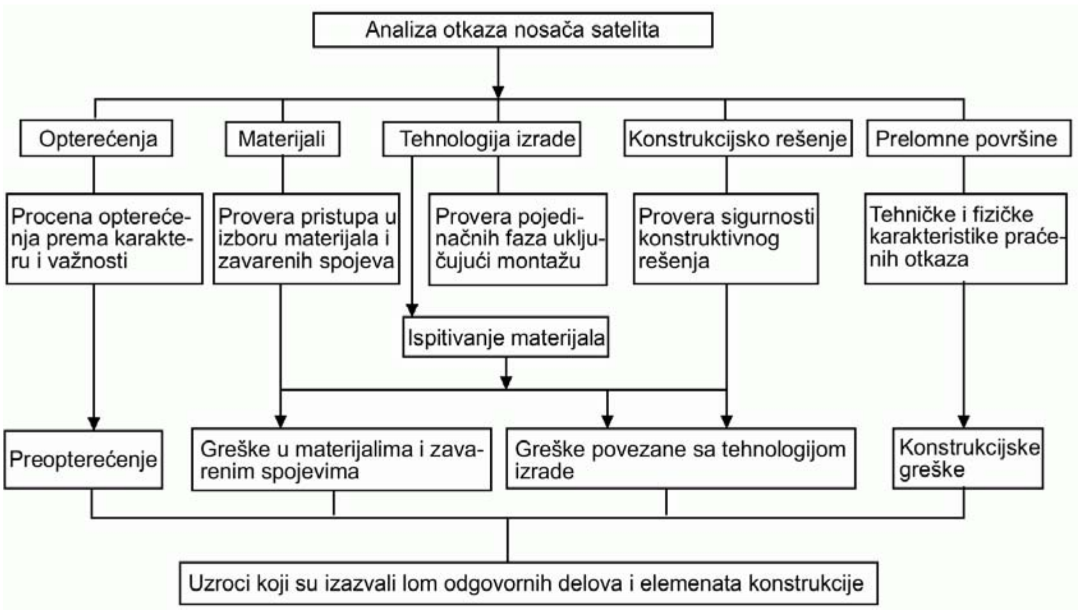
INTRODUCTION

Existing dynamic models of supporting structure, mechanisms and gear drive of bucket wheel excavators, and models of external load caused by digging resistance, do not enable an understanding of their effects on dynamic behaviour of excavator.

Premature damages of rotor bucket, arms, gear box elements and whole structures of bucket wheel excavators occur frequently in service. They are explained by inadequate design, insufficient data about parent material properties and their welded joints, and by mistakes in the manufacturing technology of elements /1,2,3/.

Failure analyses and testing of damaged and fractured components enables data for the advancement of gear box design methods, for improvement of material properties and technology, and new material development.

The scope of necessary and performed theoretical and experimental analyses of failure and component fracture of the supporting welded structure of satellite planetary gear box for the driving wheel of SRs 1300.26/5.0+VR±10 excavator is presented by the chart in Fig. 1.



Slika 1. Teorijska i eksperimentalna analiza otkaza nosača satelita planetarnog prenosnika

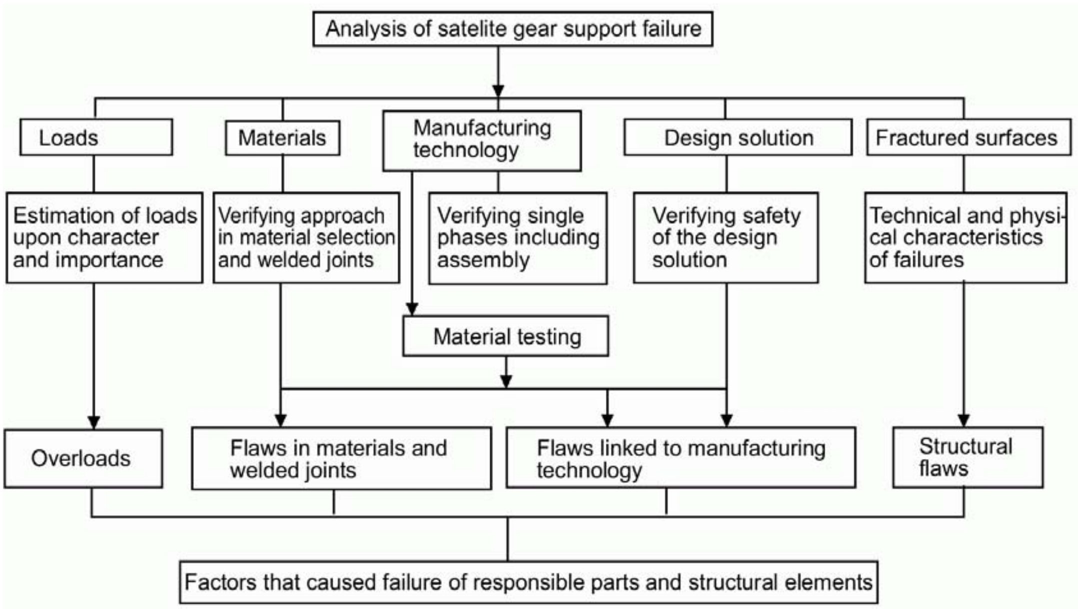


Figure 1. Theoretical and experimental failure analysis of satellite support of planetary gear box.

OSNOVNE KARAKTERISTIKE REDUKTORA

Pogonski agregat rotornog bagera SRs 1300.26/5.0+VR±10 sastoji se od elektromotora (1), hidrodinamičke spojnice (2), reduktora (3) i rotora (4), sl. 2, /4/.

Reduktor, sa planetarnim delom na izlazu, omogućava broj obrta rotora 7,108 ili 5,787 o/min, a uz pomoćni pogon 0,5 o/min. Tehničke karakteristike reduktora su: prenosni odnos i = 249,7, broj obrta elektromotora n = 1485 o/min, izlazna snaga P = 900 kW, napon U = 6000 V, maksimalna struja I = 103 A, $\cos\alpha Y$ = 0,88, izlazni moment M_i = 1374 kNm i izlazni moment pri puštanju M = 1786 kNm.

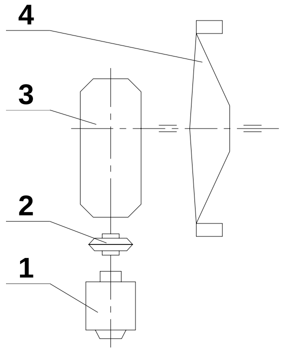
Elementi nosača zupčanika satelita su prikazani na sl. 3. Gornja prirubnica (1) je izrađena od livenog čelika GS–E 50.3, ojačavajuće rebro (2) i ploča (3) od čelika St 38b.2, a segment (4) od čelika H 52.3, prema TGL standardu.

BASIC CHARACTERISTICS OF GEAR BOX

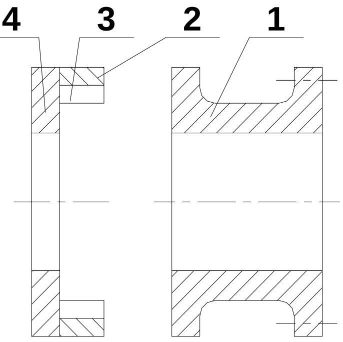
The drive unit of bucket wheel excavator SRs 1300.26/5.0+VR±10 consists of electromotor (1), hydrodynamic clutch (2), gear box (3) and rotor (4), Fig. 2, /4/.

The gear box with planetary part on the output, enables angular speed 7.108 rpm or 5.787 rpm, and with the boost drive 0.5 rpm. Technical characteristics of gear box are: reduction ratio i = 249.7, electrical motor number of revolutions n = 1485 rpm, output power P = 900 kW, voltage U = 6000 V, maximum current I = 103 A, $\cos\alpha Y$ = 0.88, output torque M_i = 1374 kNm and start-up torque M = 1786 kNm.

Components of satellite gear support are shown in Fig. 3. Upper fitting (1) is produced of cast steel GS – E 50.3, the strengthening web (2) and plate (3) of St 38b.2 steel, and the segment (4) of H 52.3 steel, according to TGL standard.



Slika 2. Shema pogonskog agregata
Figure 2. Scheme of the driving unit.



Slika 3. Elementi nosača zupčanika satelita
Figure 3. Elements of satellite gear support.

Zavarivanje delova nosača satelita je izvedeno postupcima MAG i E. Dodatni materijal je 10 MnSi, temperatura predgrevanja 150°C, termička obrada je bila žarenje na 500–550°C, a ispitivanje bez razaranja izvedeno je magnetnom metodom. Izvedeni zavareni spojevi pripadaju klasi kvaliteta II B.

TEORIJSKA ANALIZA OPTEREĆENJA REDUKTORA

Nosač satelita planetarnog dela reduktora za pogon radnog točka bagera je opterećen pogonskim momentom i poprečnim silama savijanja. Teorijska analiza napona nosača satelita izvršena je za različite slučajeve opterećenja:
– od pogonske sile,
– od sopstvene težine i naizmeničnog savijanja,
– samo od naizmeničnog savijanja.

Analiza je usmerena na sigurnost nosača satelita prema naponu tečenja i zamornoj čvrstoći od spektra opterećenja.

Opterećenje pogonskim momentom za ravnomernu raspodelu opterećenja koja deluju na uležištenja planetarnih zupčanika po obimu, F_L, izračunava se prema izrazu, /5/:

$$F_L = \frac{M_{AB}}{D_p a_p} \qquad (1)$$

gde je: M_{AB} – pogonski obrtni moment; D_p – prečnik kruga uležištenja; a_p – broj planetarnih zupčanika.

Opterećenje pogonskim momentom se prenosi preko uležištenja na ploči nosača satelita.

Uležištenje nosača satelita opterećeno je pogonskom obimnom silom i silama uležištenja u kućištu, sl. 4. i 5. Statičkim proračunom za ista nazivna opterećenja dobija se sila uležištenja $F_D = 2{,}34\cdot10^5$ N, i pri dvostrukom nazivnom opterećenju (moment spojnice) $F_D = 3{,}73\cdot10^5$ N.

Proračun radne zamorne čvrstoće gornje prirubnice (1) i segmenta (4) zavarenog nosača satelita, sl. 4, izveden je za normalnu raspodelu predviđenih spektara opterećenja. Naprezanje nosača satelita određeno je za otpor kopanju (delimični spektar 1), za oscilovanje konstrukcije u procesu kopanja (delimični spektar 2), i za promenljivo savijanja poprečnim silama (delimični spektar 3).

Naponi na najopterećenijim mestima gornje prirubnice (1) i pogonske ploče (3), σ_N, sl. 3, dati u tab. 1, određeni su kao zbir uporednih srednjih napona σ_m i uporednih amplitudnih napona σ_a korišćenjem izrazima, /6/:

Welding of the satellite support elements is performed by MAG and SMAW procedures. Consumable material is 10 MnSi, preheating temperature 150°C, heat treatment was annealing at 500–550°C, and non-destructive tests performed by magnetic particle examination. Performed welded joints belong to II B quality class.

THEORETICAL ANALYSIS OF GEAR BOX LOADING

The satellite support of planetary part of gear box used for excavator working wheel driving is loaded by the drive torque and transversal bending forces. Theoretical analysis of satellite support stress is performed for various loading:
– caused by driving force,
– by dead load and cyclic bending,
– by cyclic bending only.

The analysis is directed to the satellite support safety regarding yield stress and fatigue strength of load spectrum.

Drive torque load for uniform distribution of loads acting on the circumference of planetary gear bearings, F_L, is calculated according to expression, /5/:

$$F_L = \frac{M_{AB}}{D_p a_p} \qquad (1)$$

where: M_{AB} – driving torque; D_p – bearing diameter; a_p – number of planetary gears.

The driving torque load is transmitted through bearings on the satellite support plate.

The satellite support bearing is loaded by the circumferential driving force and bearing forces of the housing, Figs. 4 and 5. Static calculations for the same nominal loads show that the bearing force is $F_D = 2.34\cdot10^5$ N, and for double nominal load (clutch torque) $F_D = 3.73\cdot10^5$ N.

Calculation of fatigue strength of the upper fitting (1) and segment (4) of welded satellite support, Fig. 4, is performed for normal distribution of predicted spectra loads. Straining of the satellite support is determined for digging resistance (partial spectrum 1); for oscillations of the structure during the excavation process (2); and for variable bending by transversal forces (partial spectrum 3).

Stresses at maximum load location on upper fitting (1) and driving plate (3), σ_N, Fig. 3, given in Table 1, are determined as the sum of equivalent average stresses σ_m and equivalent amplitude stresses σ_a using expressions, /6/:

. $\sigma_m = \sigma_{MN}(M/M_N)$ (2)

$\sigma_a = \sigma_{QN}(M/M_N) + \sigma_{QG}$ (3)

$\sigma_o = \sigma_m + \sigma_a$ (4)

$\sigma_N = \sigma_{MN} + \sigma_{QN} + \sigma_{QG}$ (5)

gde je: σ_{MN} – uporedni napon od momenta torzije; σ_{QN} – uporedni napon od poprečnog naprezanja izazvanog obrtnim momentom; σ_{QG} – uporedni napon usled sopstvene težine; (M/M_N) – funkcija raspodele obrtnog momenta; σ_N– uporedni maksimalni napon na najopterećenijim mestima.

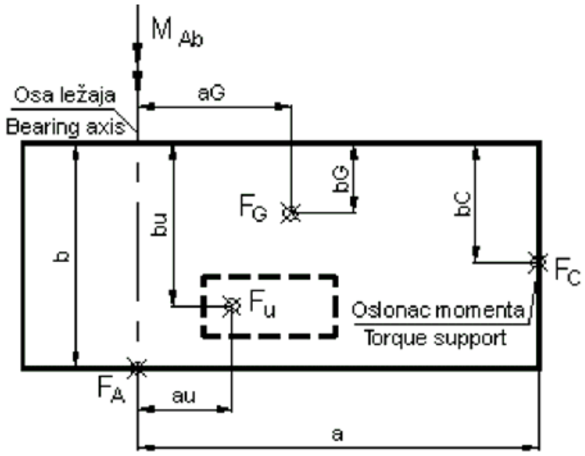
$\sigma_m = \sigma_{MN}(M/M_N)$ (2)

$\sigma_a = \sigma_{QN}(M/M_N) + \sigma_{QG}$ (3)

$\sigma_o = \sigma_m + \sigma_a$ (4)

$\sigma_N = \sigma_{MN} + \sigma_{QN} + \sigma_{QG}$ (5)

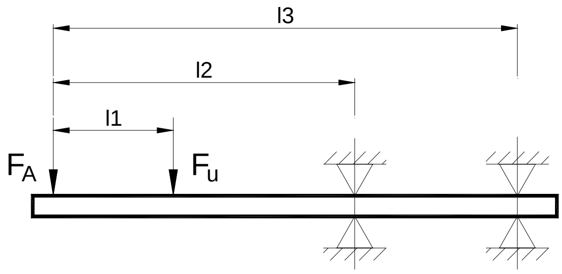
where: σ_{MN} – equivalent stress due to torque; σ_{QN} – equivalent stress of transversal straining induced by torque; σ_{QG} – equivalent stress due to dead load; (M/M_N) – torque distribution function; σ_N – equivalent maximal stress at maximal load locations.



a = 8.556 m
a_G = 1.6 m
b=1.165 m
b_C = 0.59 m
b_G = 0.58 m
b_u = 0.97 m

F_G = 260 000 N – sopstvena težina (dead load)
F_u = 332 000 N – sila zubaca (gear tooth force)

Slika 4. Raspored opterećenja kućišta reduktora, pogled odozgo
Figure 4. Load distribution on gear box housing, upper view.



l_1 = 0.203 m; l_2 = 0.446 m; l_3 = 1.080 m

Slika 5. Uležištenje i opterećenje planetarnog vratila pogonskog zupčanika
Figure 5. Bearing and loading of planetary driving gear shaft.

Tabela 1. Proračunski naponi na najopterećenijim mestima elemenata nosača satelita
Table 1. Calculated stresses at spots of maximal loads on the satellite support.

Deo (Component)	Materijal (Material)	σ_{MN}, MPa	σ_{QN}, MPa	σ_{QG}, MPa	σ_N, MPa
1	GS-E 50.3	95.2	13.7	9.3	118.2
2,3	St 38.b2	94.7	8.3	5.7	108.7

Učešće učestanosti delimičnog spektra opterećenja za promenljivo savijanje, određeno na osnovu srednjeg broja obrta rotora bagera, iznosi:

$n_R = 0{,}3\cdot 5{,}787 + 0{,}7\cdot 7{,}108 = 6{,}711$ min^{-1},

odnosno, $f_R = 0{,}119$ Hz

Za predviđeni vek trajanja od 50 000 h, pripadajući broj ciklusa opterećenja iznosi $N_3 = 2{,}01\cdot 107$, a udeo ostalih delimičnih spektara opterećenja $K_3 = 0{,}0414$. Učešće oscilatornog naprezanja izazvanog procesom kopanja u ukupnom spektru opterećenja, za funkciju raspodele $M/M_N = 0{,}35$ i učestanost $f_g = 23{\cdot}f_R = 2{,}57$, određene u funkciji zahvata kašika na rotoru, iznosi $K_2 = 0{,}952$.

Broj oscilacija u procesu kopanja, za vek L = 50 000 h, period T = 1 min, rezultuje učešćem u ukupnom spektru opterećenja sa $K_1 = 0{,}0062$.

PRORAČUN NAPONA I DEFORMACIJA PRIMENOM METODE KONAČNIH ELEMENATA

Analiza deformacija i napona nosača planetarnih satelita izvedena je metodom konačnih elemenata primenom programskog paketa „AUTRA“, razvijenog u Institutu za lake konstrukcije u Drezdenu.

The portion of partial spectrum frequency for the case of variable bending, determined as based on average angular speed of rotor amounts to:

$n_R = 0.3\cdot 5.787 + 0.7\cdot 7.108 = 6.711$ min^{-1},

thus, $f_R = 0.119$ Hz

For predicted working life of 50 000 h, the corresponding number of loading cycles is $N_3 = 2.01\cdot 107$, and the fraction of the other partial loading spectra $K_3 = 0.0414$. The fraction of oscillatory strains induced by excavation process in the total loading spectrum, for distribution function M/M_N = 0.35 and frequency $f_g = 23{\cdot}f_R = 2.57$, determined as a function of bucket digs, equals $K_2 = 0.952$.

Number of oscillations in the excavation process, for life L = 50 000 h, period T = 1 min, results in the fraction of the total load spectrum, as $K_1 = 0.0062$.

CALCULATION OF STRESSES AND STRAINS BY APPLYING FINITE ELEMENTS METHOD

The analysis of strains and stresses of planetary satellite support is performed by finite element method using application software “AUTRA”, developed by the Institute for Light Structures in Dresden.

Na sl. 6. prikazan je mrežni model za 1/4 nosača satelita. Pojednostavljena geometrijska slika proračunskog dela nosača satelita daje veće vrednosti napona od realnih pa je model prihvatljiv. Analiza naponskog stanja satelita izvedena je za različite slučajeve opterećenja. Uporedni napon σ_u za naponske koordinate je određen prema izrazu:

$$\sigma_u = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \sigma_{xy}^2} \quad (6)$$

Provera sigurnosti prema naponu tečenja

Kako program „AUTRA“ omogućava proračun maksimalnih prostornih napona, za proračun sigurnosti u odnosu na napon tečenja primenjen je postupak Seibel. On predviđa mogućnost da napon tečenja u najnapregnutijem delu konstrukcije bude prekoračen, bez vidljive deformacije, pod uslovom da zaostala deformacija zbog zatezanja bude $\varepsilon_R \leq$ 0,002. Za dati uslov, stepen sigurnosti je:

$$S_v = \frac{\delta_{0.2} \cdot \sigma_S}{\sigma_{v\,\max}} \quad (7)$$

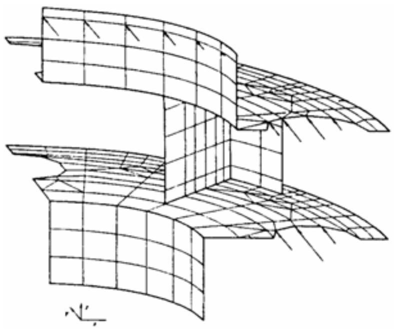
gde je: $\delta_{0,2}$ – odnos napona tečenja za kružnu prstenastu ploču pri istim uslovima opterećenja; σ_S – proračunski uporedni napon; $\sigma_{v\max}$ – maksimalni uporedni napon na makroelementu.

Odgovarajući podaci dati su u tab. 2.

Provera sigurnosti na zamor

Proračun sigurnosti na otkaz zbog zamora izveden je na bazi TGL 19340. Specifične osobine livenih materijala (GS) pogonskih ploča uzete su u obzir prema TGL 19341, a uticaj zareza prema TGL 14915.

S obzirom da svi navedeni propisi su u vezi sa koncentracijom napona, neophodna je promena u prostornim naponima dobijenim programom „AUTRA“. Zato je stepen sigurnosti za otkaz zbog zamora sračunat za čisto naizmenično promenljivo naprezanje na savijanje, uzimajući u obzir i uticaj zareza prema postupku Stilera primenom TGL 19340, i on iznosi S_D = 1,49.



Slika 6. Mrežni model nosača satelita
Figure 6. Wire frame model of satellite support.

EKSPERIMENTALNA ISPITIVANJA

Struktura raščlanjenog sistema za tenzometrijsko merenje deformacija izazvanih obrtnim momentom na pogonskom vratilu rotora bagera prikazana je na sl. 7. Korišćene su četiri merne trake tipa XY-120-HBM. Prenos električnog signala ostvaren je preko posebno projektovanih kliznih bakarnih prstenova, postavljenih na vratilu i kontaktnih grafitnih četkica, montiranih na stacionarnim nosačima, sl. 8.

Figure 6 shows the wire frame model for 1/4 of satellite support. Simplified geometry of satellite support in the calculation overestimates the stresses, so this model is acceptable. The analysis of stress state of satellite is performed for different loading cases. Equivalent stress σ_u for stress coordinates is determined using the expression:

$$\sigma_u = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \sigma_{xy}^2} \quad (6)$$

Checking of safety related to yield stress

Since software “AUTRA” enables calculation of maximal spatial stresses, Seibel’s method has been applied for the calculation of safety related to yield stress. It predicts that yield stress could be exceeded in the most stressed part of structure, without visible deformations, under the condition that residual tensile strain is $\varepsilon_R \leq$ 0.002. The safety factor in this case is:

$$S_v = \frac{\delta_{0.2} \cdot \sigma_S}{\sigma_{v\,\max}} \quad (7)$$

where: $\delta_{0.2}$ – ratio of yield stress for circular ring plate for the same loading conditions, σ_S – calculated equivalent stress, $\sigma_{v\max}$ – maximal equivalent stress in macroelement.

Corresponding data are given in Table 2.

Checking of the safety related to fatigue

Calculation of safety in relation to fatigue failure is performed based on TGL 19340. Specific cast material properties (GS) of drive plates are taken into account in accordance with TGL 19340, and notch effect with TGL 14915.

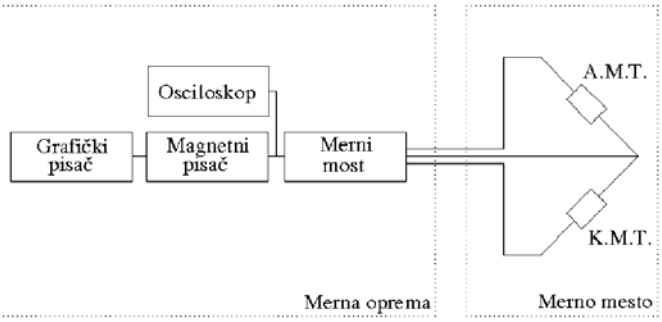
Since all mentioned codes are linked to stress concentration, it is necessary to make changes in spatial stresses obtained by “AUTRA” software. Hence, the safety factor in fatigue failure is calculated for case of pure alternate variable bending stress, taking into account notch effect in accordance to Stiler’s method using TGL 19340, and it amounts to S_D = 1.49.

Tabela 2. Podaci korišćeni za proračun sigurnosti
Table 2. Data used for calculation of safety

Element (Component)	σ_S MPa	$\sigma_{v\max}$ MPa	$\delta_{0.2}$	S_v
Prednja ploča (Front plate)	235	211	1.8	2.00
Zadnja ploča (Rear plate)	260	225.5	1.75	2.02

EXPERIMENTAL TESTS

The structure of the developed system for tensometric measurement of strains caused by torque on excavator rotor drive shaft is shown in Fig. 7. Four strain gauges, type XY-120-HBM were used. The electrical signal is transmitted by specially designed sliding copper rings, mounted on shaft and graphite contact brushes, placed on stationary supports, Fig. 8.



Slika 7. Sistem za merenje deformacija (A.M.T.–aktivna merna traka, K.M.T.–kompenzaciona merna traka)

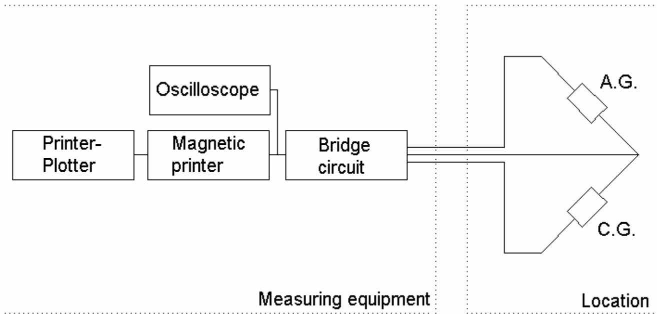
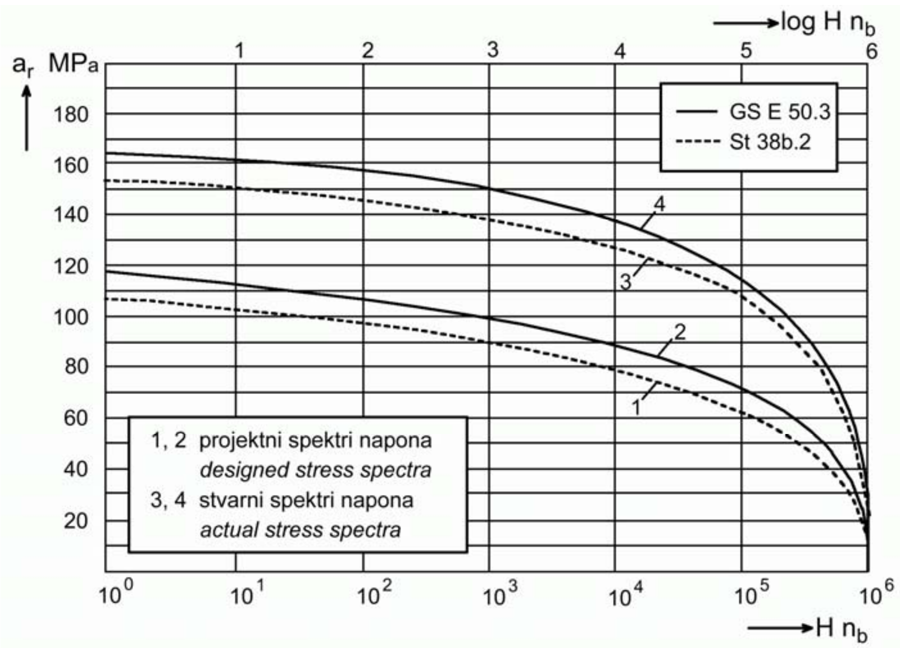


Figure 7. System for strain measurement (A.G.–active gauge, C.G.–compensation gauge).

Merenja su izvršena u različitim režimima rada bagera. Maksimalni izmereni naponi su dati u tab. 3. Spektri napona, dobijeni proračunom i na osnovu merenja deformacija, su upoređeni na sl. 9.

Measuring is performed in different regimes of excavator operation. Maximal measured stresses are given in Table 3. The stress spectra, obtained by calculation and based on strain measurements, are compared in Fig. 9.

Slika 8. Mesto postavljanja bakarnih prstenova i kontaktnih četkica
Figure 8. Placement of copper rings and graphite contact brushes.



Slika 9. Ukupni spektri napona
Figure 9. Overall stress spectra.

Tabela 3. Maksimalni naponi dobijeni eksperimentalnim ispitivanjem za različite režime opterećenja
Table 3. Maximal stresses obtained by experimental tests for different loading regimes.

Režim (Regime)	Simulirani režim rada bagera Simulated regime of excavator operation	Dobijeni napon Obtained stress
1	Pokretanje rotora na prazno – Unloaded rotor start	110 MPa
2	Opterećenje pri radu u rastresitom materijalu – Loads at excavation of loose soil	110 MPa
3	Prosečno opterećenje -mešoviti sloj otkopne mase – Average load -mixed layer of excavated mass	140 MPa
4	Rad u kompaktnoj sivoj glini – Digging of compact grey clay	165 MPa
5	Udarna opterećenja – Impact load	220 MPa

Analiza rezultata izvedenih merenja u odnosu na ostvarenu časovnu proizvodnju i svojstva otpora kopanju je pokazala da su tehničko-tehnološke karakteristike zadovoljene pri otkopu prelaznih zona između dva bloka sive gline i u rastresitim zonama, ali ne i pri otkopu kompaktne sive gline, zbog značajnih udarnih opterećenja i niskofrekventnih oscilacija.

ANALIZA PRELOMA NOSAČA SATELITA

Metalografskim ispitivanjem prelomnih površina delova nosača satelita nađena je feritno-perlitna struktura, koja odgovara osnovnom materijalu. Vizuelni pregled površina preloma prirubnice nosača satelita i analiza prostiranja prslina su ukazali na lamelarni lom materijala, sl. 10, koji polazi iz osnovnog metala ili iz zone uticaja toplote. Stepenastog je oblika i paralelan sa površinom prirubnice. Nastao je zbog tehnologije zavarivanja (termički ciklus zavarivanja), dejstva napona u pravcu debljine materijala, i konstrukcije rešenja zavarenog spoja.

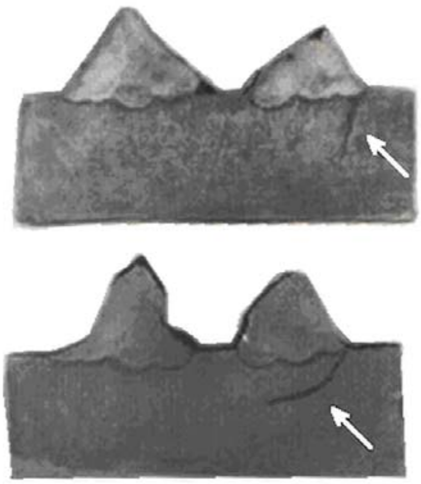
Analiza skaning elektronskim mikroskopom je otkrila heterogenu strukturu metala šava sa mnogo grešaka (greške vezivanja, prsline, uključci, gasni mehurovi), sl. 11 i 12.

Analysis of results of performed measurements in regard to the achieved hourly production and digging resistance properties have shown that technical-technological characteristics are met in excavation of transition zones between two blocks of grey clay in loose zones, but not in digging of compact gray clay, due to significant impact loads and low-frequency oscillations.

ANALISYS OF SATELLITE SUPPORT FRACTURE

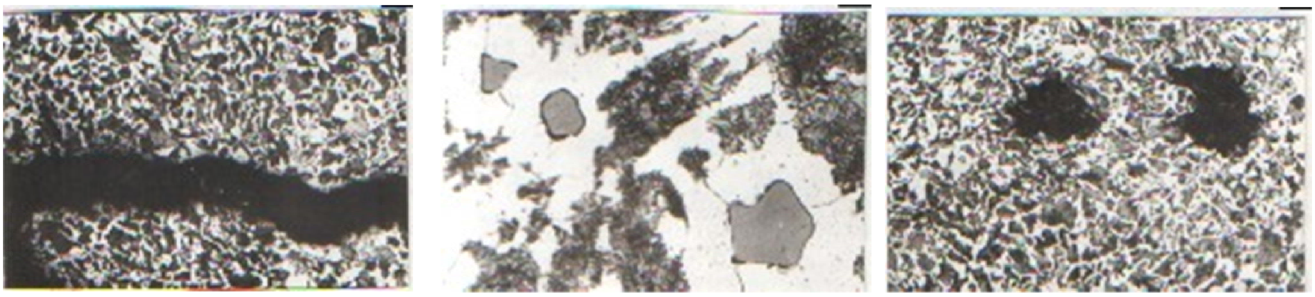
Metallographic testing of fractured surfaces of planetary gear support parts revealed a ferrite-pearlite structure, corresponding to parent materials. Visual inspection of the fractured surface of the satellite support fitting and crack propagation analysis indicated lamellar tearing of material, Fig. 10, started from parent metal or from the heat affected zone. It is step-wise and parallel to fitting surface. It was caused in the welding technology (welding thermal cycle), by stresses acting in the direction of parent metal thickness, and due from welded joint design.

Analysis by scanning electron microscope revealed heterogeneous structure of weld metal with many defects (lack of fusion, cracks, inclusions, gas cavities) Figs. 11 and 12.



Slika 10. Lamelarni lom materijala gornje prirubnice nosača satelita
Figure 10. Lamellar tearing of satellite support upper fitting.

Slika 11. Površina preloma prirubnice nosača satelita sa naznačenim pojasom niskocikličnog zamora
Figure 11. Fracture surface of satellite support fitting with indicated zone of low-cycle fatigue.



a) Metal šava sa prslinom
a) Weld metal with crack

b) Metal šava sa uključcima
b) Weld metal with inclusions

c) Metal šava sa gasnim mehurovima
c) Weld metal with gas cavities

Slika 12. Skaning elektronska mikrografija delova površine metala šava gornje prirubnice sa karakterističnim greškama
Figure 12. Electron microscopic scan of upper fitting weld metal surface with characteristic imperfections.

ZAKLJUČAK

Poređenjem spektara napona utvrđenih teorijskim razmatranjima i eksperimentalnim ispitivanjima, u odnosu na nosivost nosača satelita, utvrđeno je da su radni naponi u kritičnim presecima blizu napona tečenja, čak iako se ne uzme u obzir koncentracije napona.

Analiza konstrukcijskog rešenja elemenata nosača satelita i rezultati eksperimentalnih ispitivanja osnovnih materijala i zavarenih spojeva su pokazali da pri projektovanju i izradi zavarene konstrukcije nisu obuhvaćeni svi parametri značajni za dejstvo promenljivog opterećenja. Kod zavarenih spojeva dolazi do uticaja i koncentracija napona od promene geometrijskog oblika od grešaka u zavarenim spojevima, od kojih neke postoje u konstrukciji i pre puštanja u eksploataciju.

Proučavanje ponašanja zavarenih spojeva mora da obuhvati znatno veći broj parametara nego što je potrebno pri proučavanju čelika u vidu ploča, jer heterogenost strukture zavarenog spoja uslovljava različito ponašanje metala šava i osnovnog materijala pri dejstvu promenljivog opterećenja.

CONCLUSION

Comparison of stress spectra established by theoretical considerations and experimental tests, related to bearing capacity of satellite support, has established that working stresses in critical sections were close to yield stress, even without taking stress concentration into account.

The design solution analysis of satellite supporting elements and results of experimental tests of parent metals and welded joints have shown that all parameters significant for variable load application had not been included in the design and manufacture of the welded structure. Stress concentrations in welded joints appear as a result of variations of shape geometry and as a result of imperfections in welded joints, of which some remain inside the structure even before exploitation.

Studies of welded joint behaviour should comprise of a significantly larger number of parameters than necessary for studying steel plates because welded joint structural heterogeneity causes different behaviour of weld metal and parent metal at applied variable loading.

LITERATURA – REFERENCES

1. Džoni, A., *Teorijska i eksperimentalna analiza stanja u zavarenim spojevima konstrukcije radnog točka rotornog bagera*, Magistarski rad, Mašinski fakultet, Skoplje, 1985.
2. Arsić, M., *Teorijska i eksperimentalna analiza stanja zavarene kašike rotornog bagera*, Magistarski rad, Mašinski fakultet, Skoplje, 1986.
3. Arsić, M., *Korelacija zamorne čvrstoće i praga zamora zavarenih spojeva*, Doktorska disertacija, Priština, 1995.
4. TAKRAF SRs 1300.26/5.0+VR±10: Dokumentacija proizvođača opreme.
5. Gnilke, W., *Lebensdauerberchnung der Maschinenelemente*, VEB Verlag, Technik, Berlin, 1981.
6. Standards: TGL 19340, TGL 19341, TGL 14915