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Provera statičke stabilnosti rotornog bagera putem vaganja – merenja težine gornje obrtne gradnje

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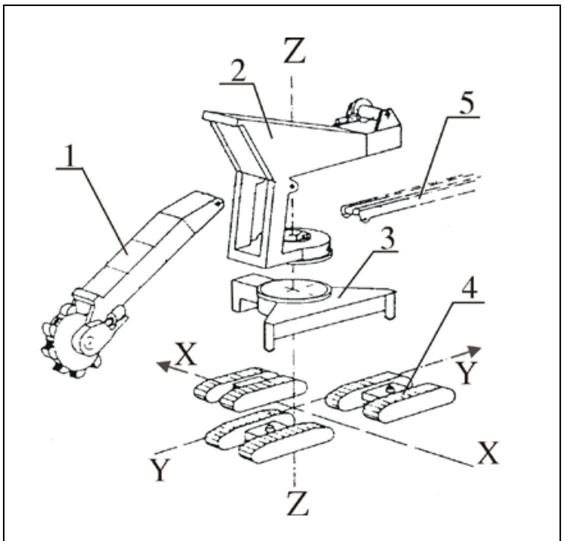
Vaganje je važna i kompleksna oblast nauke o merenju. Danas se pod vaganjem podrazumeva postupak merenja težine, a ovom problematikom su se bavili najveći umovi svojih vremena. Provera statičke stabilnosti rotornog bagera odnosno određivanje težine i položaja težišta gornje obrtne gradnje vrši se eksperimentalnim putem - vaganjem. Može se reći da se eksperimentalni metod široko koristi u nauci i tehnici. Upravo masovna primena eksperimenata, nužno je izazvala naučni pristup eksperimentu: eksperiment je postao objekat naučnog istraživanja. Njime se bavi posebna disciplina - matematička teorija eksperimenata. Ona predstavlja savremenu naučnu disciplinu i deo je opšte teorije eksperimenata. Obe ove teorije (matematička i opšta teorija eksperimenata) sastavni su delovi eksperimentalnog metoda kao osnovnog naučnog metoda.

Ključne reči: vaganje, statička stabilnost, rotorni bager, gornja obrtna gradnja, merenje.

1. UVOD

Po svojoj funkcionalnosti i dimenzijama, rotorni bageri, slika 1, pripadaju klasi najsloženijih i najvećih rudarskihmašina.



Slika 1. Osnovni delovi rotornog bagera; 1 – strela rotora; 2 – gornja gradnja; 3 – donja gradnja; 4 – gusenični mehanizam za kretanje; 5 – odložna traka.[1]

Sva opterećenja koja deluju na rotorni bager svrstavaju se u dve osnovne grupe i to:

- stalna opterećenja i
- povremena opterećenja.

Stalna opterećenja predstavljaju opterećenja izazvana težinama delova noseće konstrukcije, uređaja i mehanizama bagera. Na osnovu podataka o težinama i položajima njihovih napadnih linija, na osnovu Varinjonove teoreme, određuje se položaj težišta bagera. S obzirom da činjenicu da se parametri koji definišu položaj težišta ne mogu sa dovoljnom tačnošću odrediti u fazi projektovanja mašine, nakon izvršene montaže vrši se eksperimentalno određivanje težine i položaja težišta.

Povremena opterećenja (otpor kopanja, težina transportovanog materijala, težina kore, opterećenja od dejstva vetra, ...) javljaju se, pod određenim uslovima, u toku eksploatacije mašine.

Statička stabilnost mašine obezbeđena je ukoliko se napadna linija rezultante svih sila nalazi unutar konture oslanjanja.

Stepen sigurnosti protiv prevrtanja mašine oko uočene ose, definiše se količnikom momenta sila koje se suprotstavljaju prevrtanju (stabilizacioni moment - M_S) i momenta sila koje teže da naruše statičku stabilnost (moment prevrtanja - M_K), $\nu_{PRE} = M_S / M_K$.

Prema [2], brojne vrednosti stepena sigurnosti protiv prevrtanja zavise od skupa opterećenja koja se razmatraju u datom slučaju. Skupovi opterećenja nazivaju se slučajevima opterećenja. Prema citiranoj literaturi, razlikuju se četiri slučaja opterećenja bagera i to:

- slučaj opterećenja H, kada osim stalnih opterećenja, na mašinu deluju i opterećenja izazvana:
  - težinom transportovanog materijala;
  - težinom kore;
  - otporom kopanja;
  - nagibom planuma;
  - promenom hoda trake;
- slučaj opterećenja HZ, kada, osim opterećenja koja deluju u slučaju H, na mašinu deluju i opterećenja izazvana:
  - vetrom;
  - snegom i ledom;
  - temperaturskim promenama;
- slučaj opterećenja HZS u kome se, osim opterećenja navedenih slučaju HZ, ali sa većim intenzitetima, razmatraju i opterećenja koja nastaju pri:
  - zagušenju levka;
  - delimičnom oslanjanju rotora na planum;
  - kretanju bagera.

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- slučaj opterećenja HZG u kome se, pored ekstremnih kombinacija navedenih opterećenja, razmatra i uticaj opterećenja izazvanih zemljotresom.

Minimalne vrednosti stepena sigurnosti iznose [2]:

- slučaj opterećenja H - ν_{PRE} = 1,5;
- slučaj opterećenja HZ - ν_{PRE} = 1,3;
- slučaj opterećenja HZS - ν_{PRE} = 1,2;
- slučaj opterećenja HZG - ν_{PRE} = 1,1.

U literaturi [3] se navode sledeće minimalne vrednosti stepena sigurnosti protiv preturanja:

- ν_{PRE} = 1,25 – kada se bager nalazi u radnom i transportnom položaju;
- ν_{PRE} = 1,15 – u ekstremnim slučajevima i tokom montaže.

Specifičnost rotornih bagera u odnosu na problem statičke stabilnosti je posledica promenljivosti geometrijske konfiguracije gornje gradnje - strela rotora, odložna strela, obrtna stolica. Dakle, i položaj težišta same nadgradnje je promenljiv, kao i položaj napadnih linija povremenih opterećenja koja koja deluju na pomenute delove bagera. Zato se pri dokazu statičke stabilnosti u razmatranom slučaju opterećenja, mora odabrati i najnepovljnija geometrijska konfiguracija nadgradnje.

Provera statičke stabilnosti vrši se u ravnima koje definišu veze pojedinih vitalnih elemenata strukture bagera, slika 2. Pomenute veze su:

- veza gornje i donje gradnje koja se ostvaruje radiaksijalnim ležajem;
- veza donje gradnje i guseničnog mehanizma za kretanje.
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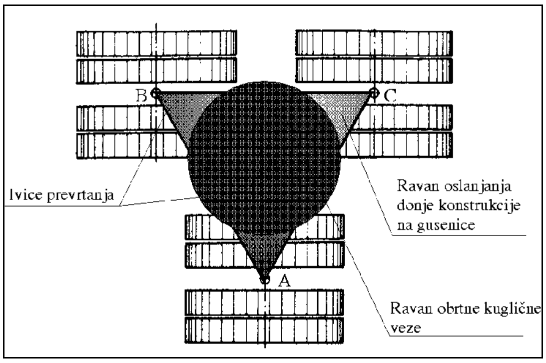
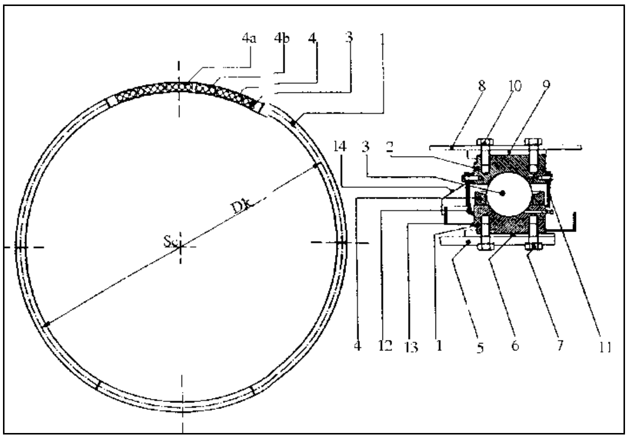


Slika 2 – Ravni oslanjanja gornje gradnje

Kod velikih rotornih bagera (veliki kapacitet i masa – bageri IV i V klase), uravnotežavanje konstrukcionih elemenata nadgradnje ostvaruje se na posebno oblikovanoj ploči – tzv. razdelna ploča, zbog čega se kod njih statička stabilnost dokazuje i u ravni pomenute ploče.

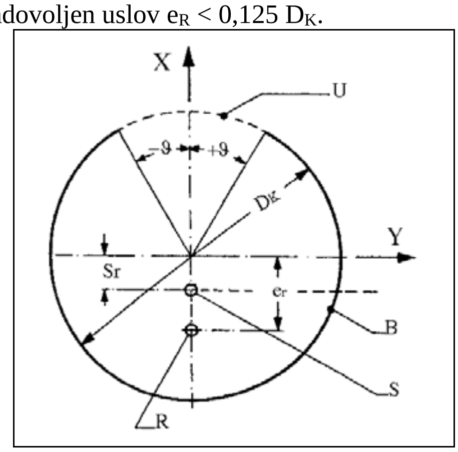
2. DOKAZ STABILNOSTI U RAVNI RADIAKSIJALNOG LEŽAJA GORNJE GRADNJE

Celokupna gornja gradnja oslanja se na donju gradnju posredstvom radiaksijalnog ležaja, slika 3. Njegova uloga je da na donju gradnju prenese sva opterećenja koja deluju na gornju gradnju i osim toga, omogući njeno okretanje u odnosu na donju gradnju.



Slika 3. Radiaksijalni ležaj nadgradnje; 1 i 2 - donji i gornji prsten; 3 - kugla; 4 - kavez; 4a i 4b - kavez za izjednačenje broja kugli; donja gradnja; 6, 9 - podloga; 7, 10 - zavrtanj; 8 - gornja gradnja; 11, 12 - zaptivka; 13 - kanal za ulje; 14 – zaštita;[1]

Raspodelu opterećenja po kuglama definiše opterećenje ležaja – glavni vektor i glavni moment koji se dobijaju rekukcijom opterećenja gornje gradnje na ishodište usvojenog sistema referencije. Ukupna vertikalna sila Fz i moment Mxy su međusobno upravni, tako da je njihov uticaj ekvivalentan uticaju sile Fz kada njena napadna linija prolazi kroz tačku R, slika 4, koja se nalazi na rastojanju e_R od koordinatnog početka. Neravnomernost raspodele opterećenja kugli dominantno zavisi od pomenutog opterećenja. Ukoliko ukupna vertikalna sila deluje unutar jezgra preseka (krug poluprečnika 0,125 D_K), sve kugle učestvuju u prenošenju opterećenja. U protivnom, deo kugli i donjeg prstena, ostaje neopterećen, slika 4. Upravo zbog toga, treba težiti da za slučajeve opterećenja koji se često javljaju u radu bude zadovoljen uslov $e_R < 0{,}125\ D_K$.



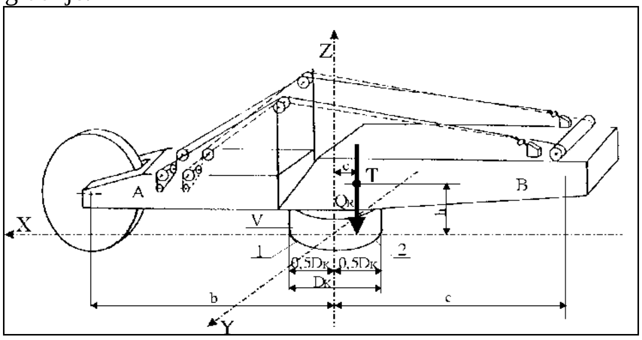
Slika 4. Opterećenje radiaksijalnog ležaja nadgradnje; U – neopterećena zona; B – opterećena zona; S – težište opterećene zone prstena; R – prodor napadne linije vertikalnog opterećenja; θ – ugao koji definiše neopterećenu zonu;[1]

Kontura oslanjanja u ravni radiaksijalnog ležaja jeste kružnica prečnika D_K, slika 5. Liniju prevrtanja definiše njena tangenta u referentnoj tački.

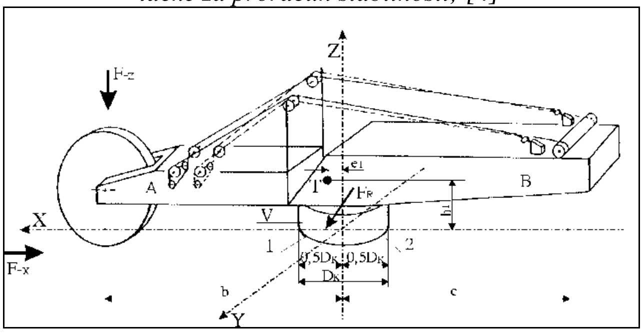
Opterećenja koja deluju povremeno, uslovljavaju promenu položaja napadne linije opterećenja radiaksijanog ležaja, slika 6.

Sobzirom na činjenicu da se težište gornje gradnje nalazi relativno visoko u odnosu na ravan oslanjanja, slika 5, prilikom dokaza stabilnosti. Osim toga, zbog velikih površina delova strukture bagera, uticaj opterećenja izazvanih vetrom i snegom, takođe se mora uzeti u obzir.

Da bi se sprečio gubitak statičke stabilnosti, pogon rotora se izvodi sa odgovarajućom zaštitom koja sprečava pojavu prekomernih opterećenja. Osim toga, ugradnjom kandži koje onemogućavaju dekompoziciju (otvaranje) ležaja, znatno se podiže pouzdanost mašine u odnosu na preturanje. One se aktiviraju u trenutku otvaranja ležaja. Jasno, njihovo dejstvo je ograničeno samo na one slučajeve opterećenja kod kojih ne postoji okretanje gornje gradnje.



Slika 5. Gornja gradnja bagera; A – strela rotora; B – protivteg; V – venac; T – težište; D_K – prečnik konture oslanjanja; Q_R – težina nadgradnje; 1, 2 – referentne tačke za proračun stabilnosti; [4]



Slika 6. Uticaj povremenog opterećenja na položaj napadne linije rezultante; A – strela rotora; B – protivteg; V – venac; D_K – prečnik konture oslanjanja; F_R – rezultanta opterećenja ležaja; 1, 2 – referentne tačke za proračun stabilnosti;[4]

3. MERENJE TEŽINE I ODREĐIVANJE POLOŽAJA TEŽIŠTA GORNJE GRADNJE BAGERA

Postupak merenja težine i određivanja položaja težišta gornje gradnje zasniva se na određivanju reakcija njenih oslonaca. Na osnovu višegodišnjeg iskustva, koncipiran je postupak merenja sa dva nezavisna merna lanca. Time se obezbeđuje neophodna tačnost i pouzdanost rezultata merenja.

Prvi merni lanac je zasnovan na merenju sile putem merenja pritiska hidrauličnog ulja u hidrauličnoj dizalici. Naime, gornja obrtna gradnja rudarskih mašina se podiže uz pomoć hidrauličnih cilindara – dizalica, uz istovremeno merenje pritiska u njima. Na osnovu izmerenih vrednosti pritisaka i poznate površine klipa hidrocilindra, određuju se intenzitet reakcije posmatranog oslonca.

Drugi merni lanac je zasnovan na merenju sile putem elektrootpornih mernih ćelija. Naime, na hidraulične cilindre, uz pomoć kojih se podiže gornja obrtna gradnja, postavljaju se elektrootporne merne ćelije. To je, u stvari, metalni elastični cilindar po čijem su obodu zalepljene elektrootporne merne trake. Veza mernih traka je ostvarena preko Vitstonovog mosta. Deformacije tela merne ćelije (cilindra), prenose na merne trake, usled čega one menjaju svoju otpornost. Promena otpornosti trake je proporcionalna njenoj deformaciji, pa se njenim merenjem može odrediti intenzitet sile. Pomenuta promena se detektuje univerzalnim mernim pojačalom i računarskom obradom pretvara u intenzitet sile u mernoj tački.

Sabiranjem intenziteta izmerenih reakcija oslonaca, dobija se ukupna težina gornje obrtne gradnje rudarske mašine. Položaj projekcije težišta na ravan radiaksijalnog ležaja („kuglbana”) određuje se primenom Varinjonove teoreme.

3.1 Uslovi izvođenja merenja

Sud o valjanosti rezultata merenja može da se donese samo ukoliko oni mogu da se uporede sa nekim referentnim vrednostima. Za referentne vrednosti usvajaju se vrednosti koje su dobijene računskim putem, ili vrednosti koje su dobijene pri nultom merenju (merenje neposredno nakon montaže rudarske mašine). Da bi se rezultati mogli porediti, neophodno je rudarsku mašinu dovesti u isti položaj kao i pri nultom merenju, ili u položaj pri kome je proračunom, u fazi projektovanja, utvrđen položaj težišta.

Pre samog početka merenja neophodno je da budu ispunjeni sledeći uslovi:

- planum na kome se vrši merenje mora da bude nivelisan (nagib manji od 1 : 300), obeležen i pripremljen za proces merenja;
- brzina vetra mora biti manja od 6 – 10 m/s;
- vremenske prilike treba da budu bez atmosferskih padavina;
- rudarska mašina mora da se nalazi u unapred definisanom položaju (vrši se kontrola položaja strele rotora, strele kabine rukovaoca, pretovarnog uređaja, odložne trake, krana, obrtne stolice, ...);
- transportne trake moraju da budu prazne;
- kora, ostaci transportovanog materijala i nečistoće moraju da budu uklonjeni;
- vezni elementi uređaja za nošenje napojnog kabla moraju da budu demontirani;
- zaštitni obuhvatni prsten radiaksijalnog ležaja mora da bude demontiran;
- zaštita zupčastog venca u području kuka – hvataljki, kao i zaptivka obrtne kuglične veze i kuka – hvataljki mora da bude demontirana;
- zazor između zupčastog venca i malih zupčanika pogona okretanja gornje gradnje mora da bude proveren;
- obrtanje gornje gradnje mora da bude onemogućeno, što se postiže blokiranjem kočnica;
- kočnice mehanizma za kretanje mašine moraju da budu postavljene u odgovarajući položaj;
- dovod struje visokog napona do mašine mora da bude isključen.

U toku priprema za izvođenje merenja mora da se onemogući:

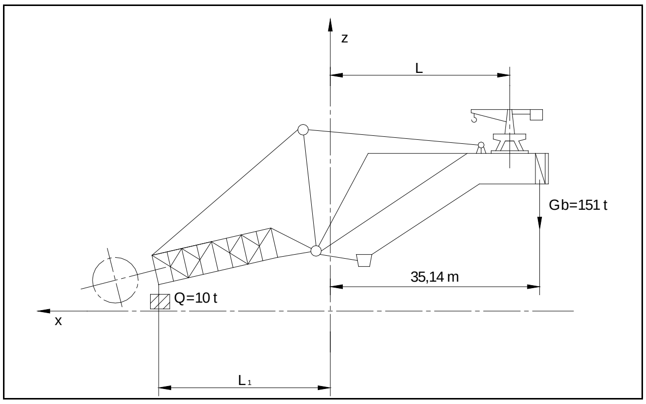
- kretanje teške mehanizacije i kamiona u blizini rudarske mašine;
- prisustvo osoba koje nisu neposredno angažovane na izvođenju pojedinih operacija merenja.

3.2 Tehnološki postupak merenja

Merenje težine gornje obrtne gradnje rudarskih mašina se vrši u nekoliko faza, pri različitim položajima i opterećenjima strele rotora. Merni položaji strele rotora, koji zavise od vrste rudarske mašine, mogu da budu: donji, horizontalni i gornji.

3.2.1 Prva faza merenja

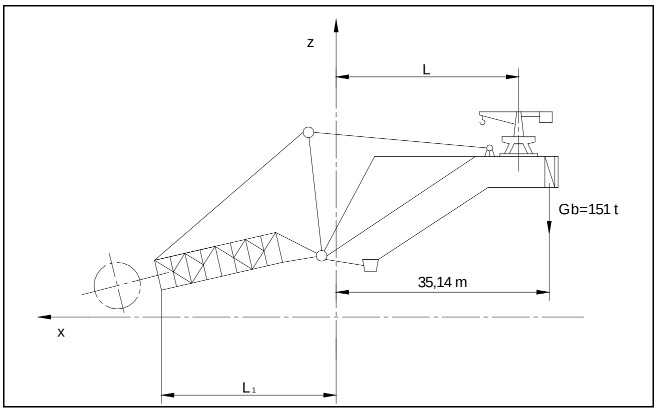
Strela rotora nalazi se u donjem položaju, pri čemu se donja ivica rotora nalazi na rastojanju ≈ 1m iznad planuma, slika 7. U zoni poprečnog rama 1 opterećena je etalon – teretom, čija je masa (reda veličine 10 t) određena merenjem na baždarenoj vagi. Ova faza merenja izvodi se sa ciljem da se izvrši kalibrisanje i kontrola tačnosti mernog sistema.



Slika 7. Prva faza merenja

3.2.2 Druga faza merenja

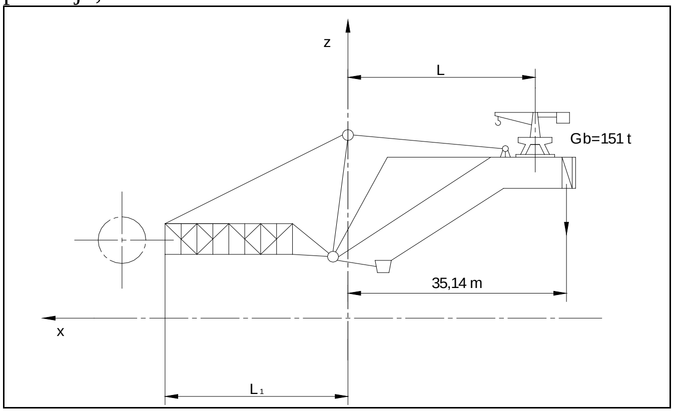
U drugoj fazi merenja, slika 8, strela rotora nalazi se u donjem položaju, bez etalon – tereta.



Slika 8 – Druga faza merenja

3.2.3 Treća faza merenja

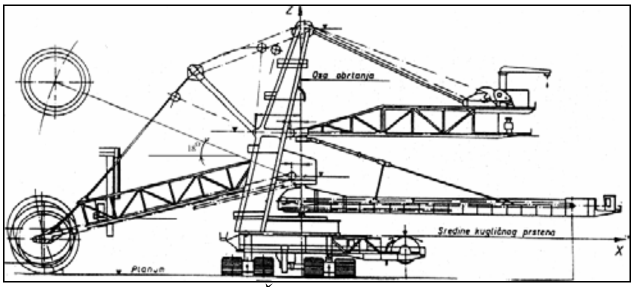
Strela rotora, slika 9, nalazi se u horizontalnom položaju, bez etalon – tereta.



Slika 9. Treća faza merenja

3.2.4 Četvrta faza merenja

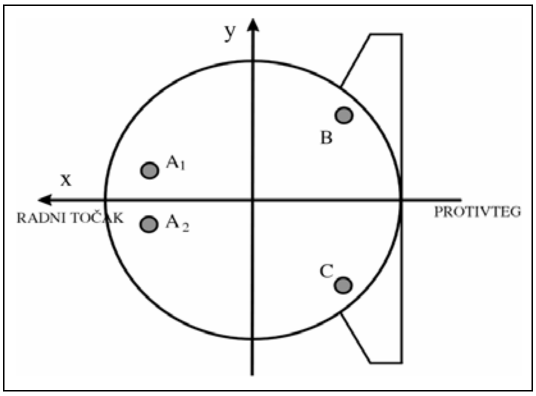
Strela rotora, slika 10, nalazi se u gornjem položaju (ugao nagiba u odnosu na horizontalu ≈ 18°), bez etalon – tereta.



Slika 10. Četvrta faza merenja

3.2.5 Redosled podizanja oslonaca

Raspored oslonaca (mernih mesta) gornje gradnje prikazan je na slici 11. Hidrocilindri u osloncima A_1 i A_2 su hidraulično spojeni, čime se obezbeđuje njihov sinhronizovan rad.



Slika 11. Dispozicija oslonaca gornje gradnje (mernih mesta)

Prvo se podižu oslonci ka protivtegu, slika 11, i to oslonac C za 3 mm, a zatim oslonac B za 3 mm**.** U oba slučaja sigurnosna navrtka mora da se priteže, tako da osim elemenata hidrostatičkog sistema (hidraulično ulje, priključci, spojnice) opterećenje preuzima i sigurnosna navrtka. Zatim se podižu oslonci ispod strele rotora (A_1 i A_2) za 3 mm.

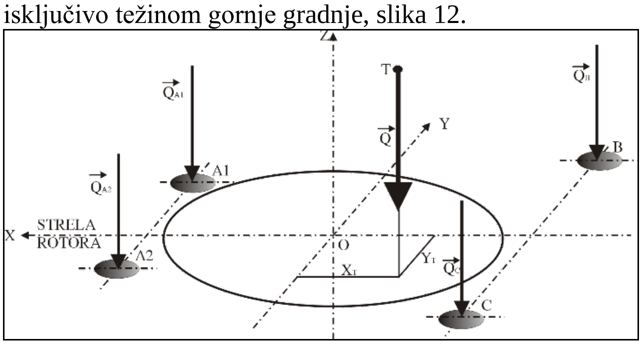
Sporovođenjem navedene procedure podiže se gornja gradnja za ≈ 20 mm, čime se obezbeđuje potpuno rasterećenje radiaksijalnog ležaja. Pri tome, nakon poslednjeg ciklusa podizanja, ne vrši se pritezanje sigurnosnih navrtki čime se obezbeđuje da celokupnu težinu nadgradnje preuzimaju hidrocilindri. U tom položaju očitavaju se vrednosti pritisaka u hidrocilindrima (prvi merni lanac) i intenziteti reakcija oslonaca dobijenih koričćenjem drugog mernog lanca. Dobijeni podaci predstavljaju „nulto stanje merenja".

Da bi se eleiminisao uticaj greške koja se javlja u prvom mernom lancu (trenje između klipa i cilindra), u svim fazama merenja, sprovodi se sledeći postupak:

- podizanje oslonaca u redosledu C, B i A (A_1 i A_2), za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac);
- spuštanje oslonaca u redosledu A (A_1 i A_2), B i C, za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac);
- podizanje oslonaca u redosledu B, A (A_1 i A_2) i C, za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac);
- spuštanje oslonaca u redosledu C, A (A_1 i A_2) i B, za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac);
- podizanje oslonaca u redosledu A (A_1 i A_2), C i B, za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac);
- spuštanje oslonaca u redosledu B, C i A (A_1 i A_2), za po 2 mm, uz očitavanje pritisaka (prvi merni lanac) u hidrocilindrima i intenziteta reakcija oslonaca (drugi merni lanac).

3.3 Izračunavanje težine i položaja težišta gornje gradnje rotornih bagera

Pri obezbeđenim neophodnim uslovima za izvođenje merenja, opterećenja oslonih tačaka izazvana su isključivo težinom gornje gradnje, slika 12.



Slika 12. Shema za određivanje težine i položaja težišta gornje gradnje

S obzirom na činjenicu da su intenziteti opterećenja oslonaca gornje gradnje jednaki intenzitetima odgovarajućih reakcija koje se mere, njena težina se izračunava na osnovu izraza

$$Q = Q_{A1} + Q_{A2} + Q_B + Q_C ,$$

u kome su Q_{A1}, Q_{A2}, Q_B i Q_C opterećenja oslonih tačaka.

Položaj projekcije težišta gornje gradnje na raferentnu raven (ravan radiaksijalnog ležaja) određuje se primenom Varinjonove teoreme,

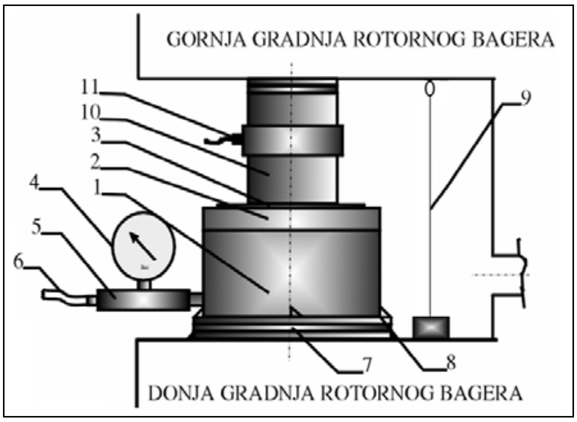
$$X_T = (\Sigma Qi \times Xi) / Q ,$$

$$Y_T = (\Sigma Qi \times Yi) / Q ,$$

pri čemu se koordinate oslonaca gornje gradnje (Xi i Yi) određuju geodetskim merenjem.

4. MERNI SISTEMI I OPREMA

Pre početka merenja, mašina mora da se nalazi u položaju koji je propisan od strane proizvođača („remontni položaj"). Nakon toga se u prostor između odgovarajućih oslonaca na donjoj i gornjoj gradnji postavljaju hidrocilindri sa mernim ćelijama. Izgled mernog mesta prikazan je na slici 13.



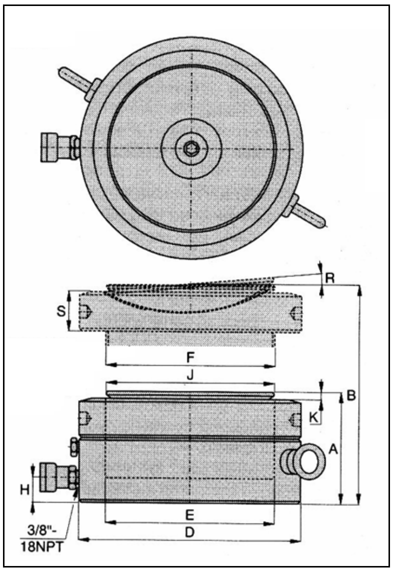
Slika 13. Merno mesto; 1 – hidrocilindar; 2 – sigurnosna navrtka; 3 – klip hidrocilindra; 4 – manometar; 5 specijalna spojnica; 6 – crevo; 7 kompenzacioni limovi; 8 graničnici; 9 – davač pomeranja; 10 – merna ćelija; 11 – električni priključak

4.1 Hidrocilindar

Kod oba merna lanca, hidrocilindri služe kao podizači gornje gradnje. Istovremeno, u prvom mernom lancu (hidraulični) koriste se i kao davači pritiska, čija se vrednost očitava na manometru.

Za obavljanje merenja koriste se hidrocilindri Enerpac CLP – 5002, slika 14, sa maksimalnom silom potiskivanja 5000 kN. Osnovni tehničke karakteristike hidrocilindra date su u tabeli 4.1.

Pre početka merenja, mora se izvršiti baždarenje hidrocilindara.



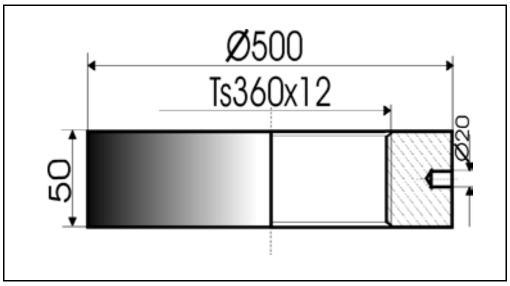
Slika 14. Hidrocilindar CLP – 5002

Tabela 4.1

Hod (mm)	45
Sila (kN)	5114
Efektivna površina (cm²)	730,6
Zapremina cilindra (cm³)	3287
A (mm)	192
B (mm)	237
D (mm)	400
E (mm)	305,0
F (mm)	Tr 305 x 6
H (mm)	48
J (mm)	290
K (mm)	10
R	3⁰
S (mm)	62
Masa (kg)	150

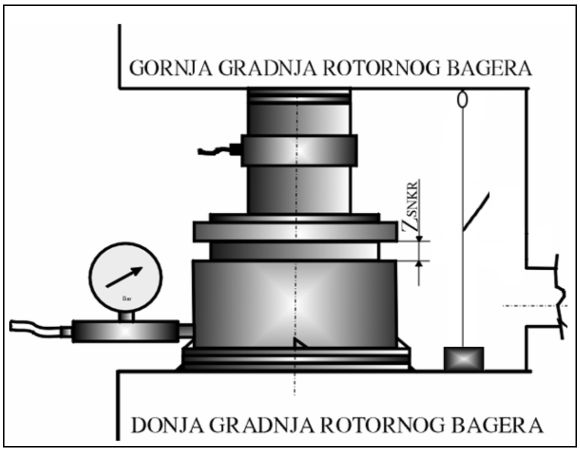
4.2 Sigurnosna navrtka

Zadatak sigurnosne navrtke, slika 15, jeste da spreči neželjeno povratno kretanje klipa i omogući delimično rasterećenje elemenata hidrostatičkog sistema. Ona tokom procesa podizanja gornje gradnje „prati“ kretanje klipa, sve dok se ne ostvari potpuno rasterećenje radiaksijalnog ležaja.



Slika 15. Sigurnosna navrtka

Nakon rasterećenja radiaksijalnog ležaja, navrtka je van funkcije, a maksimalna vrednost aksijalnog zazora između nje i tela hidrocilindra iznosi ≈ 2mm, slika 16. Na taj način se sprečava da u slučaju otkaza neke komponente hidrostatičkog sistema dođe do gubitka statičke stabilnosti mašine.



Slika 16. Položaj sigurnosne navrtke nakon rasterećenjaradiaksijalnog ležaja

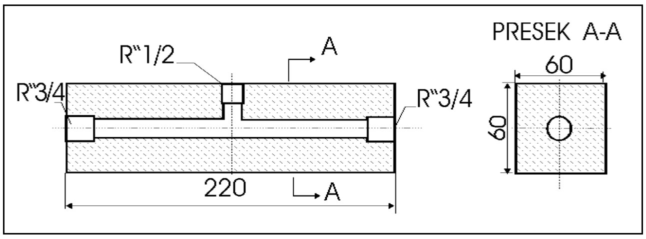
4.3 Manometar

Svaki hidrocilindar opremljen je baždarenim manometrom. Ovi manometri moraju da ispunjavaju sledeće zahteve:

- klasa tačnosti – 1;
- merni opseg – do 600 bar;
- podeona skala – 1 ... 5 bar;
- izvedena zaštita od hidrauličnih udara.

4.4 Sigurnosna spojnica

Za potrebe meranja, razvijena je specijalna spojnica, slika 17, sa zaptivnim prstenom, koji sprečava nekontrolisano kretanje ulja.



Slika 17. Sigurnosna spojnica

4.5 Hidraulična creva

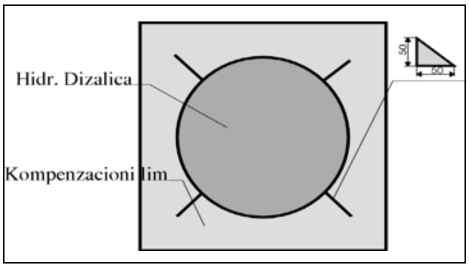
Povezivanje komponenti hidrostatičkog sistema ostvaruje se odgovarajućim crevima, radnog pritiska 700 bar.

4.6 Kompenzacioni limovi

Hidrocilindri se postavljaju na slog limova, slika 13, koji su međusobno, i sa osloncem na donjoj gradnji, zavareni. Lim na koji se postavlja hidrocilindar mora da bude besprekorno čist i odmašćen.

4.7 Graničnik

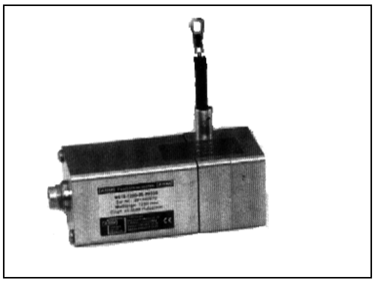
Da bi se sprečilo nekontrolisano horizontalno pomeranje tela hidrocilindra, na gornji kompenzacioni lim zavaruju se odgovarajući graničnici, slika 18.



Slika 18. Raspored graničnika

4.8 Davač pomeranja

Ukoliko je podizanje gornje gradnje podržano računarom, koristi se davač pomeranja prikazan na slici 19. Njegovo telo se postavlja neposredno uz hidrcilindar, a uže se vezuje za gornju gradnju. Hod užeta iznosi 500 mm.

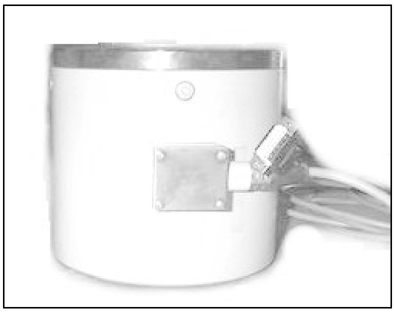


Slika 19. – Davač pomeranja

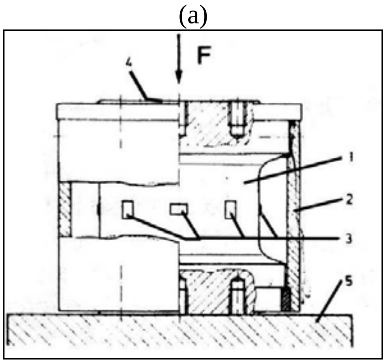
Kada se za podizanje gornje gradnje koristi ručno upravljani hidraulični agregat, očitavanje pomeranja vrši se na posebno konstruisanom lenjiru.

4.9 Davač sile

Osnovu drugog (električnog) mernog sistema čini davač sile (merna ćelija) HBM – C6. Njen oblik i struktura prikazani su na slici 20.



(a)



(b)

Slika 20. Merna ćelija; (a) – Izgled; (b) – Struktura; 1 – telo (merni cilindar); 2 – zaštitni oklop; 3 – merne trake; 4 – uvodnik opterećenja; 5 - podloga

Oblik, dimenzije i konstrukcija merne ćelije moraju da zadovolje sledeće uslove:

- linearna zavisnost deformacija od intenziteta opterećenja, uz uniformnu raspodelu napona;
- što manji histerezis;
- što manja osetljivost na temperaturske uslove;
- mogućnost postavljanja u prostor relativno malih dimenzija.

Da bi se ostvarilo potpuno i centrično naleganje gornje gradnje na mernu ćeliju, kao i naleganje merne ćelije na donju gradnju, koriste se posebno oblikovani elementi – uvodnik opterećenja i podloga.

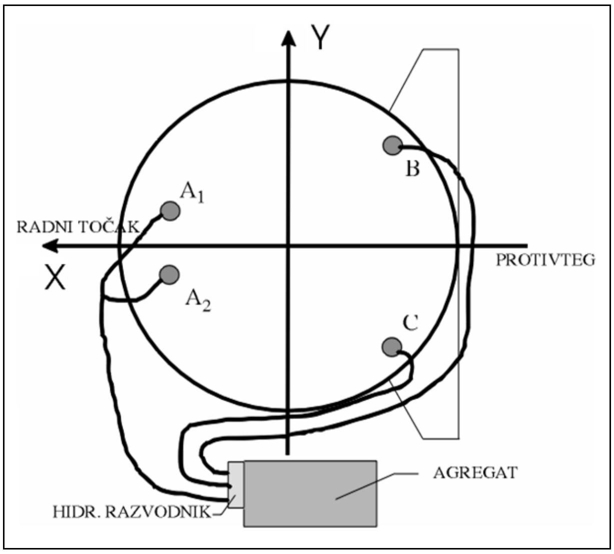
Davač sile prikazan na slici 20 omogućava i merenja u vremenskom domenu. To znači da je moguće meriti intenzitete reakcija oslonaca gornje gradnje i tokom rada rudarske mašine, ukoliko to nije ograničeno njenom koncepcijom.

4.10 Hidraulični agregat

Za podizanje nadgradnje koriste se:

- hidraulični agregat sa ručnim upravljanjem;
- hidraulični agregat sa računarskim upravljanjem.

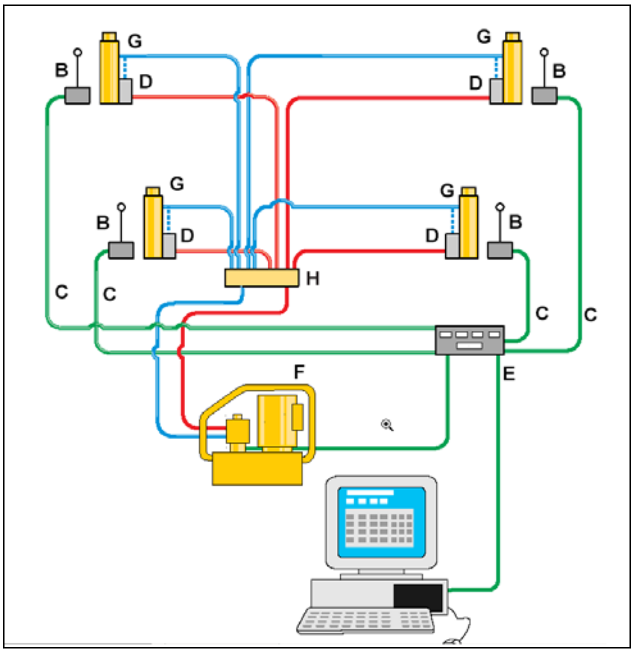
Hidraulični agregat, maksimalnog radnog pritiska 630 bar, protoka 6,6 *l*/min, postavlja se na gornju platformu ili planum. Način povezivanja agregata sa hidrocilindrima u osloncima gornje gradnje, prikazan je na slici 21.



Slika 21. Povezivanje hidroagregata

Računarski upravljani agregat (maksimalni radni pritisak 700 bar), sa svim elementima sistema za podizanje, prikazan je na slici 22. Funkcionalne veze pojedinih elemenata sistema date su na slici 23. Razmatrani sistem omogućava sinhrono podizanje svih oslonaca gornje gradnje, uz istovremeno praćenje odstupanja. Ukoliko razlika pomeranja pojedinih oslonaca prekorači unapred definisanu vrednost, sistem se automatski isključuje.

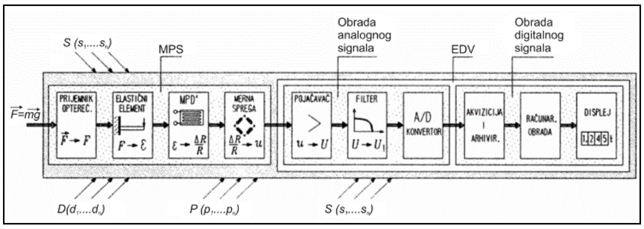
Slika 22. Elementi sistema za sinhrono podizanje gornje gradnje



Slika 23. Funkcionalna shema sistema za sinhrono podizanje; A – upravljačka jedinica; B – davač pomeranja; C – električni kabl; D – creva; E – razvodna kutija; F – pumpa; G – hidrocilindar; H – razvodnik

4.11 Merni sistem i obrada signala

U osnovi, merni sistem čine: merni pretvarač sile (merna ćelija) i elektronski deo, slika 24. Na posmatrani sistem, pored težine, deluju: vektor $\vec{D}$ koji reprezentuje nepovoljne efekte prijema i transfera spoljašnjeg opterećenja, vektor parazitskih opterećenja $\vec{P}$ i vektor $\vec{S}$ koji predstavlja razne spoljašnje uticaje.



Slika 4. Funkcionalna shema mernog sistema[5]

Tela mernih ćelija deformišu se pod dejstvom opterećenja izazvanog težinom gornje gradnje. Deformacija se prenosi na merne trake, što izaziva poremećaj ravnoteže Vitstonovog mosta i pojavu signala na njegovom izlazu. Pomenuti signal je relativno slab, reda veličine mV, zbog čega je neophodno izvršiti njegovo pojačanje. To se ostvaruje pomoću operacionih pojačavača u vidu integrisanih kola. Osnovni zahtevi koje mora da ispuni pojačavač su:

- velika ulazna otpornost;
- stabilno pojačanje;
- izraženu linearnost;
- nizak nivo šuma;
- slabu osetljivost pojačanja i nule na temperaturu.

Šum i eventualne smetnje otklanjaju se primenom elektronskih filtara, koji se postavljaju u mrežnom delu (uklanjaju smetnje koje dolaze od napajanja), na ulazu mernog pojačavača (filtar za frekventnu selekciju signala) i na ulazu u A/D konvertor (eliminacija naizmenične komponente signala).

Transformacija analognog u digitalni signal ostvaruje se u A/D konvertoru. Ona se, u osnovi, svodi na kvantifikaciju signala u frekventnom domenu. Digitalni signal je znatno pogodniji od analognog zbog: manje osetljivosti na spoljašnje uticaje i znatno lakše obrade.

Merenja su izvedena primenom univerzalnog mernog pojačavača HBM MGC+, slika 25, podržanog lap – top računarom. Prikazani uređaj omogućava istovremeno merenje na 128 nezavisnih kanala, koji su opremljeni nezavisnim pojačavačima i internim CPU. Kontrola i upravljanje radom univerzalnog mernog pojačala, akvizicija i numeričko i grafičko prikazivanje rezultata, ostvaruje se odgovarajućim softverom.

Slika 25. Univerzalno merno pojačalo MGC+

5. MERENJE TEŽINE I ODREĐIVANJE POLOŽAJA TEŽIŠTA GORNJE GRADNJE ROTORNOG BAGERA KRUPP SchRs 1760

Da bi se ostvarila željena tačnost rezultata merenja, neophodno je rigorozno sprovesti proceduru koja obuhvata:

- pripremu planuma („placa“) na kome će se vršiti merenja;
- pripremu i postavljanje bagera u merni položaj;
- postavljanje merne opreme;
- obavljanje merenja.

5.1 Priprema terena

Pre postavljanja mašine planum se mora izravnati, pri čemu maksimalni dozvoljeni nagib iznosi 1:300.

5.2 Priprema i postavljanje bagera u merni položaj

Priprema bagera obuhvata:

- demontažu zaštite zupčastog venca u području kuka – hvataljki, kao i zaptivki obrtne kuglične veze i kuka hvataljki;
- sprečavanje obrtanja gornje gradnje, što se postiže aktiviranjem odgovarajućih kočnica;
- proveru zazora između zupčastog venca i malih zupčanika pogona okretanja nadgradnje;
- postavljanje kočnica guseničnih kretača u odgovarajući položaj;
- isključenje visokonaponskog dovoda električne energije.

Merenja se izvode u sledećem položaju mašine, slika 26:

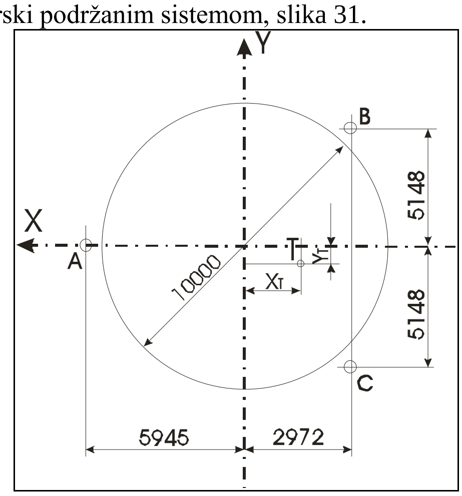
- odložna traka zaokrenuta za ugao od 100° u odnosu na osu konzole protivtega;
- strela rotora i strela kabine rukovaoca postavljene u planumski položaj;
- pretovarni uređaj postavljen u krajnji položaj;
- eliminacija uticaja pretovarnog uređaja ostvaruje se postavljanjem podupirača na rastojanju ~11200 mm od ose radiaksijalnog ležaja, slika 27.

Slika 26. Bager u mernom položaju

Slika 27. Oslanjanje pretovarnog uređaja

5.3 Postavljanje merne opreme

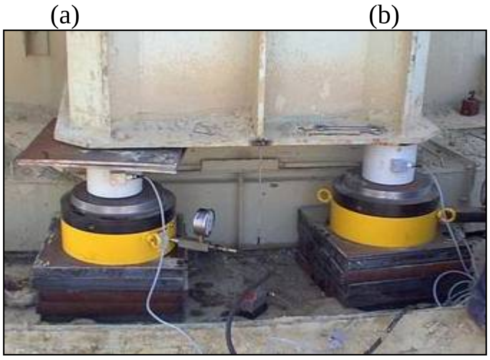
U mernim tačkama A, B i C, slika 28, postavljena su po dva hidraulički spojena hidrocilindra (Enerpac CLP – 5002, maksimalna sila 5000 kN) sa mernim doznama (HBM – C6, merni opseg 0 do 5000 kN), slike 29 i 30. Sinhronizovano podizanje gornje gradnje ostvaruje se računarski podržanim sistemom, slika 31.



Slika 28. Raspored mernih mesta

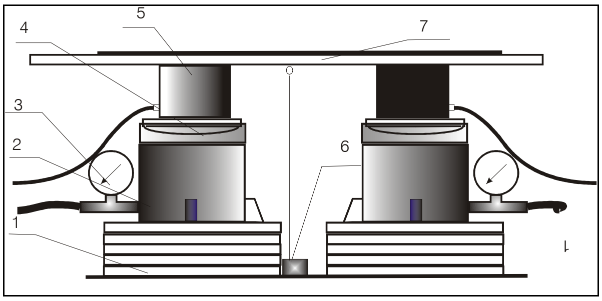
(a)

(b)



(c)

Slika 29. Izgled mernog mesta A (a), B (b) i C (c)



Slika 30. Strukturna shema jednog mernog mesta: 1 – lim (paket); 2 – hidrocilindar; 3 – manometar; 4 – kalota; 5 – merna dozna; 6 – davač pomeranja; 7 – gornja gradnja;

Slika 31. Sistem za sinhrono podizanje i merno pojačalo

5.4 Postupak merenja

Prilikom izvođenja merenja, strela rotora i strela kabine rukovaoca bagera postavljaju se u donji položaj, pri čemu je donja ivica rotora postavljena na ≈ 500 mm od planuma.

Prva serija merenja izvodi se sa kontrolnim tegovima ukupne mase 13,6 t, koji se vešaju za prvi ram strele rotora (gledano ka zglobnoj vezi pete strele rotora), slika 32. Rasterećenje radiaksijalnog ležaja ostvaruje se sinhronim podizanjem gornje gradnje (ukupno 15 mm), uz dotezanje sigurnosnih navrtki na klipnjačama hidrocilindara. Nakon toga se vrši vizuelna kontrola rasterećenja kotrljajnih tela radiaksijalnog ležaja, slika 33. Zatim se tačke oslanjanja sinhrono podižu za 2 mm bez dotezanja sigurnosne navrtke. Taj nivo se usvoja za referentnu ravan merenja. Nakon očitavanja intenziteta opterećenja u oslonim tačkama (≈ 100 vrednosti) A, B i C, vrši se sinhrono spuštanje oslonih tačaka za 2 mm od nivoa referentne ravni. Posle izvršenog merenja, gornja gradnja se spušta na donju gradnju.

Slika 32. Položaj kontrolnih tegova

Slika 33. Vizuelna kontrola rasterećenja kotrljajnih tela radiaksijalnog ležaja

Nakon skidanja kontrolnih tegova, izvodi se druga serija merenja po istoj proceduri.

5.5 Rezultati merenja

Rezultati prve i druge serije merenja obavljenih dati su u tabelama 5.1 i 5.2, respektivno:

Tabela 5.1 (sa kontrolnim tegom):

Opterećenja oslonaca [kN]			Ukupna težina [kN]	X_T	Y_T
F_A	F_B	F_C	*kN*	*m*	*m*
7111.3	4136.3	4527.7	15775.3	1.05	-0.13
7093.1	4147.4	4535.3	15775.8	1.04	-0.13
7081.6	4152.7	4542.2	15776.5	1.03	-0.13
7080.6	4153.0	4544.2	15777.7	1.03	-0.13
7104.4	4138.1	4532.7	15775.2	1.04	-0.13
7096.0	4141.8	4537.5	15775.4	1.04	-0.13
7085.4	4148.0	4543.9	15777.3	1.03	-0.13
7082.7	4148.7	4544.5	15775.9	1.03	-0.13
7086.5	4147.8	4540.5	15774.8	1.03	-0.13
7093.3	4145.6	4536.3	15775.1	1.04	-0.13
7110.6	4138.1	4527.6	15776.4	1.05	-0.13
7124.5	4129.4	4520.9	15774.9	1.06	-0.13
7129.9	4125.4	4518.7	15774.1	1.06	-0.13
Srednje vrednosti			**Q_1=15776.0**	**X_T = 1.05**	**Y_T = -0.13**

Tabela 5.2 (bez kontrolnog tega):

Opterećenja oslonaca [kN]			Ukupna težina [kN]	X_T	Y_T
F_A	F_B	F_C	*kN*	*m*	*m*
6397.0	4414.5	4806.8	15618.3	0.68	-0.13
6378.6	4426.4	4817.8	15622.7	0.67	-0.13
6375.4	4429.0	4820.9	15625.3	0.67	-0.13
6379.1	4425.3	4815.9	15620.3	0.67	-0.13
6412.5	4402.2	4795.6	15610.3	0.69	-0.13
6423.8	4396.1	4789.5	15609.5	0.70	-0.13
6437.6	4387.1	4781.8	15606.6	0.71	-0.13
6439.8	4386.1	4781.1	15607.0	0.71	-0.13
6432.3	4390.0	4784.1	15606.4	0.70	-0.13
6415.0	4401.6	4795.4	15612.0	0.69	-0.13
6404.4	4408.6	4802.4	15615.4	0.69	-0.13
6394.5	4415.6	4808.0	15618.2	0.68	-0.13
6380.2	4424.9	4815.6	15620.6	0.67	-0.13
Srednje vrednosti			**Q_2 = 15614.0**	**X_T = 0.69**	**Y_T = -0.13**

6. ZAKLJUČAK

Dobijeni rezultati merenja, vaganja, gornje obrtne gradnje rotornog bagera KRUPP SchRs 1760 iznose:

težina gornje obrtne gradnje: Q=1561,4 t
projekcije težište: Xt=690 mm i Yt=-130 mm

i pokazuju da su rezultati Xt i Yt u granicama dopuštenog +-Dk/4 tj. +-2500 mm što čini da je statička stabilnost gornje obrtne gradnje rotornog bagera u zoni stabilnosti i nema opasnosti od prevrtanja ni potrebom za korekcijom težina u protivtegu bagera.

ZAHVALNICA

Rad predstavlja deo istraživanja obavljen u okviru projekta TR 35006. Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Republike Srbije.

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Checking of Statistic Stability of Bucket-wheel Excavator Through Weighing – Measuring Weight of Upper Working Construction

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Weighing is important component in science measuring. Now days under weighing is included procedure of measuring weight, and on this problem were working some of the greatest minds of our times. Checking of statistic stability of bucket wheel excavator i.e. determination weight and position of brunt of working upper construction is proceed in experimental way – weighing. We could say that experimental method is used in science and technique. Just that massive use of experiments has developed science approach to experiment: experiment has become an object of science research. He's developed by special science discipline – mathematical theory of experiments. That brings to modern science discipline and its part of general theory of experiments. Both of these theories (mathematical and general theory of experiments) are components of experimental method as general science method.

Keywords: weighing, static stability, bucket-wheel excavator, upper construction, measuring.

1. INTRODUCTION

By their function and dimensions, bucket-wheel excavator, image 1, are in class for most complex and biggest mining machinery.

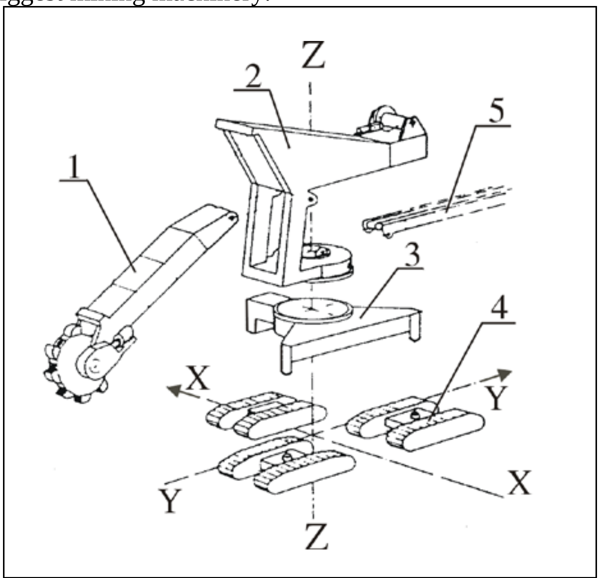

Figure 1. Main parts of bucket-wheel excavator; 1 – the arrow of rotor; 2 – upper construction; 3 – lower construction; 4 – the caterpillar mechanism for moving; 5 – deponent lane; [1]

All loads which impact to bucket-wheel excavator are listed in two groups:

- Permanent loads, and
- Temporary loads.

Permanent loads are presenting all loads made by weight parts of supporting structure, devices and mechanism of excavator. Based on data about weight and position of theirs attack lines, based on Varin's theorem, shall be determined the position and brunt of excavator.

Considering the fact that given parameters which define position of brunt can't be exactly determined in phase of projecting machine, after completed montage it begin with experimental determination of weight and position of brunt.

Temporary loads (digging resistance, weight of transported material, weight of crust, loads of wind power, etc.) are noticed in certain conditions during machines exploitation.

Statistic stability of machine is insured if the attack line of resultant all forces are inside contour of reliance.

Security level against machines rollover through determined ax are defined by quotient of moment forces which are opposed to rollover (moment of stabilization-M_S) and moment forces which threat to break down statistic stability (moment of rollover - M_K), $\nu_{PRE} = M_S / M_K$.

According to [2], many values of security level against rollover depend on sets of loads which are going to be proceeded in given case. Sets of loads are named as cases of loads. According to cited literature there are four different cases of loading the excavator:

- Case of load H, when except the constant loads on machine effect also and loads caused by:
  - Weight of transported material
  - Weight of crust;
  - Resistance to digging;
  - Tilting of the formation;
  - Changing the work of the lane;
- Case of load HZ, when except loads which effect on case H, machine is effected and loaded by:
  - wind;
  - ice and snow;
  - big temperature differences;
- Case of load HZS in which, except loads mentioned in case HZ but with bigger intensities are considered and loads which are resulting in:
  - congestion funnel;

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- partial tilting the brunt on formation;
- movement of excavator;
- Case of load HZG in which, through extreme combination of mentioned loads are considered and influence loads effects by earthquake.

Minimal values of security level are: [2]:

- Case of load H - $\nu_{PRE} = 1,5$;
- Case of load HZ - $\nu_{PRE} = 1,3$;
- Case of load HZS - $\nu_{PRE} = 1,2$;
- Case of load HZG - $\nu_{PRE} = 1.1$;

In literature [3] is spoken about next minimal values of security level against rollover:

- $\nu_{PRE} = 1.25$ – when the excavator is in working and transporting position;
- $\nu_{PRE} = 1.15$ – in extreme cases during montage.

The specific of bucket-wheel excavator relative to problem of statistic stability is effect of changeable geometrical configuration of upper construction – the arrow of rotor, deponent arrow and rotating chair. So, the position of brunt of the upgrades is changeable, also as position of attack lines of temporary loads which effects on mentioned parts of excavator. Therefore, the proof of statistic stability in considered case of loads must choose the worst geometrical configuration of upgrades.

Checking the statistic stability is proceeded in flat lines which defines relations of some vitals elements of excavator structure, fig. 2. Mentioned relations are:

- Relation of upper and lower construction, which is completed by radial-axial bearing;
- Relation of lower construction and caterpillar's mechanism for moving.

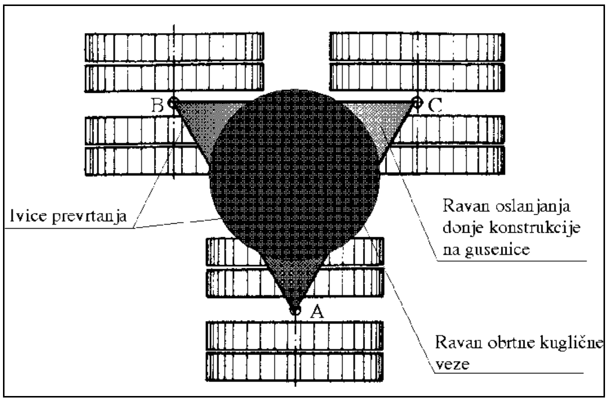


Figure 2. Flat lines of reliance of upper construction;

In massive bucket-wheel excavators (big capacity and weight – excavator IV and V class), balancing of constructive elements of construction are accomplished on specific shaped panel – i.e. divide panel, which for their statistic stability is improved in flat of mentioned panel.

2. PROOF OF STABILITY IN FLAT LINE OF RADIAXAL BEARING OF UPPER CONSTRUCTION

Whole upper construction is reliance to upper construction through radial-axial bearing, image 3.

His part is that on lower construction pass on all loads which impact on upper construction also, to allow her rotating in position of lower construction.

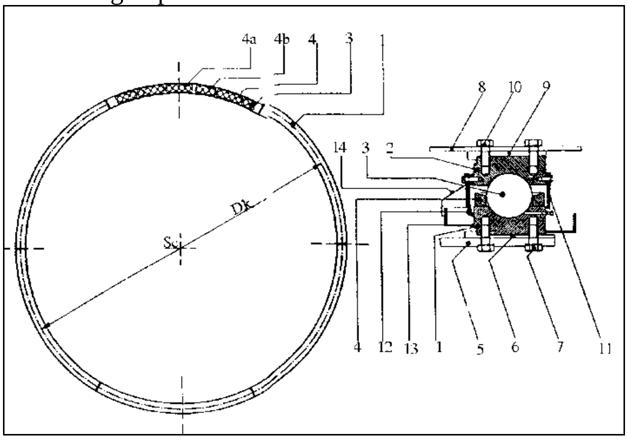


Figure 3. Radial-axial bearing of upgrade: 1 and 2 – upper and lower ring; 3 - ball; 4 - cage; 4a and 4b – cage for equipotential number of balls; lower construction; 6, 9 - base; 7, 10 - screw; 8 – upper construction; 11, 12 - gasket; 13 – canal for oil; 14 – security; [1]

Distributing load by balls defines bearing loads – main vector and main moment which are made by reduction of loads of upper construction at adopted system of references. Whole vertical force F_z and moment M_{xy} are mutual administrative, so their impact is equivalent impact to the force of F_z when their attack line is going through dot R, image 4, which is positioned on distance e_R from coordinate beginning. Uneven from distributing loads by balls dominant depending on mentioned loads. If whole vertical force is acting inside core section (around radius 0,125 D_K), all balls are included in transferring load. If not, part of balls of the lower ring stays unloaded, image 4. Just for that, you should pay attention to cases of loads which are usual in work because they should be satisfied with the requirement of $e_R < 0,125\ D_K$.

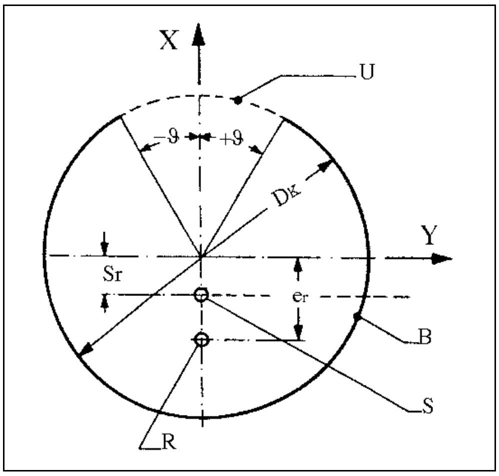


Figure 4. The load of radial-axial bearing of construction; U – unloaded zone; B – loaded zone; S – brunt of the loaded zone of ring; R – impact of the attack line of vertical loads; θ –angle which defines unloaded zone; [1]

The contour of leaning in line of radial-axial bearing is circular radius D_K, image 5. The line of rollover is defined by her tangent in referent dot.

The loads with temporary impact, are causing the change of position of attack line of loads of radial-axial bearing, fig. 6. Considering the fact that brunt of the upper construction is stationed high relative on flat line of leaning, fig. 5, during evidence of stability the term must considered the not efficient impact of tilt of formation. Before that, big surface area of parts of excavator structure are impacted of loads caused by wind and snow, also should be considered.

To stop the loose of statistic stability of operation of bucket-wheel excavator is proceeded with appropriate security which stops excessive loads. Also the mounting of the claws which prevent decomposition of bearing that is a significant reliability of machine's positioning the rollover. They're activated in moment of opening the bearing. Understandable, their effect is limited only to the cases of loads which don't consider rolling of upper construction.

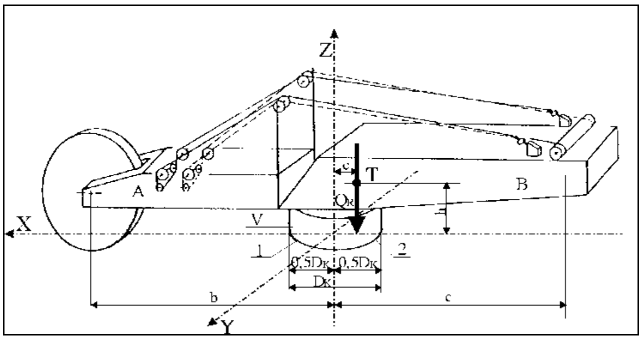


Figure 5. Upper construction of excavator; A – the arrow of rotor; B – counterweight; V – wreath; T – brunt; D_K – diameter contour of leaning; Q_R – weight of construction; 1, 2 – referent dots for stability estimate; [4]

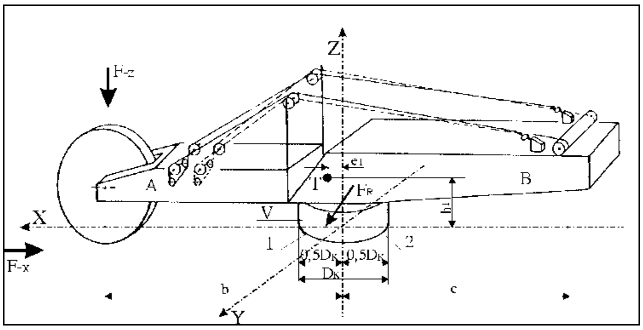


Figure 6. Influence of temporary loads at resultant attack line; A – Arrow of the rotor; B – Counterweight; V – Wreath; D_K – Diameter contour of leaning; F_R – Resultant loads of bearing; 1, 2 – Referent dots for stability estimate; [4]

3. MEASURING OF WEIGHT AND DETERMINATION OF BRUNT'S POSITION AND UPPER EXCAVATOR CONSTRUCTION

Procedure of weight measuring and determination of brunt's position of upper construction are based on determination of reaction of their holders. Based on years of experience it's conceived measuring concept with two independent chain.

First measuring chain is based on measuring of force through measuring of pressure of hydraulic oil in hydraulic crane. The upper rotating construction of mining machinery is lifted up with help of hydraulic cylinder – cranes, at the same time with measuring pressure in them. Based on measured values of pressure and known area of hydraulic cylinder piston, then determination of intensity of reaction of watched support.

Second measured chain is based on measuring pf force through measured cells with electric resistance. On hydraulic cylinders with whose help is lifted the upper rolling construction, the cells above are positioned. Basically that's metal elastic cylinder on whose brim is tied electric resistance measuring tapes. Relation of measuring tapes is accomplished through Vat's Bridge. Deformation of bodies of measuring cells (cylinder) are transferred to measured tapes, due to they change their resistance. Change of resistance of tape is proportional to her deformation, so with their measure we can adjust the force intensity. Mentioned change is detected with universal measurement amplifier and with computer it's becoming in intensity of force in measured dot.

Summing of measured intensities of leaners reaction, we're given overall weight of upper rolling construction of mining machinery. The position of projection on flat line of radial-axial bearing are determined with Varian's theorem.

3.1Conditions of performing measuring

The judgment about results of measuring can be given only in case if they can be compared to some referent values. For referent values we adjust the values which are produced through zero measuring (measuring that is immediately after montage of mining machine). That the result can be compared it's necessary that the mining machine is driven into the same position as was in zero measuring, or in position in which as by calculation, in phase of projecting as termed the position of brunt.

Before start measuring its necessary to be fulfilled certain conditions:

- Formation at which is proceeded the measuring must be leveled (the gradient should be less than 1:300), marked and prepared for measuring process.
- The wind speed should be less than 6 – 10 m/s;
- The weather conditions should be without any rainfall;
- The mining machine must be ready in advanced defined position (control of position of arrow of bucket wheel, arrow of the personnel cabin, reloading device, deponent lane, crane, rolling chair must be carried out)
- Transport lanes must be emptied;
- Crust, leftovers of transported material and dirt must be removed;
- Protective comprehensive ring of radial-axal bearing must be dismantled;
- The protection of geared wreath in area of hooks – catchers, also and gaskets of rolling ball relation and hooks – catchers must be dismantled;
- The clearance among geared wreath and small gears of operators of rolling of upper construction must be checked;
- The rolling of upper construction must be disabled, what's achieved blocking of brakes;

- The breaks of moving mechanism must be positioned in right direction;
- The power supply of high voltage through machine must be dismantled;

In preparation for performing of measuring must be enabled:

- Moving of hard mechanization and trucks near mining machine;
- The presence of persons who are not directly involved on performing of some parts of measuring;

3.2 Technological process of measuring

Measuring of the weight of upper rolling construction of mining machines is proceeded through few phases, with different positions and loads of the arrow rotor. Measuring position of rotor's arrow which depends on type of mining machine can be: upper, horizontal and lower.

3.2.1 First measuring phase

The arrow of rotor is located in lower position, whereby the lower edge of rotor is based on distance of ≈ 1m beneath formation, fig. 7. In zone of cross-ram 1 loaded is etalon – load, which mass is (of the order 10 t) is defined by measuring on calibrated scale. This phase of measuring is performed with the goal of performing calibration and control of liquids in measuring system.

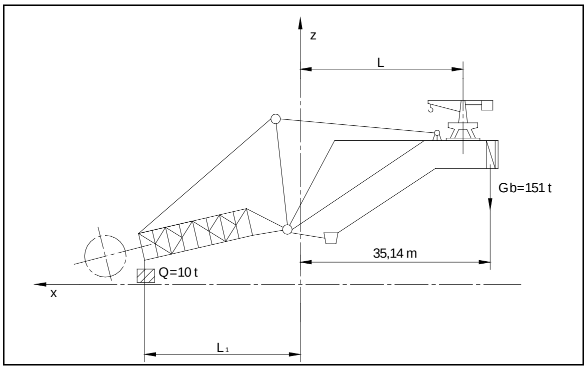


Figure 7. First phase of measuring;

3.2.2 Second phase of measuring

In second measuring phase, fig. 8, the arrow of rotor is located in lower position, b etalon – load.

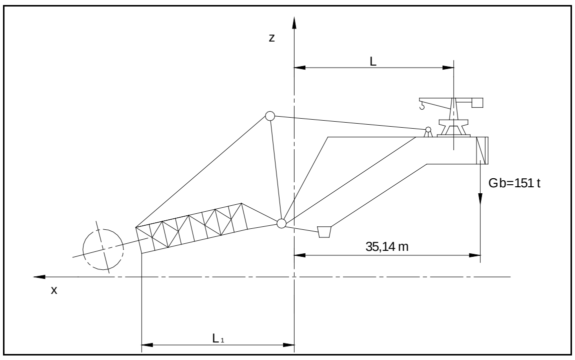


Figure 8. Second measuring phase;

3.2.3 Third measuring phase

The arrow of rotor, fig. 9, is located in horizontal position, without etalon – load.

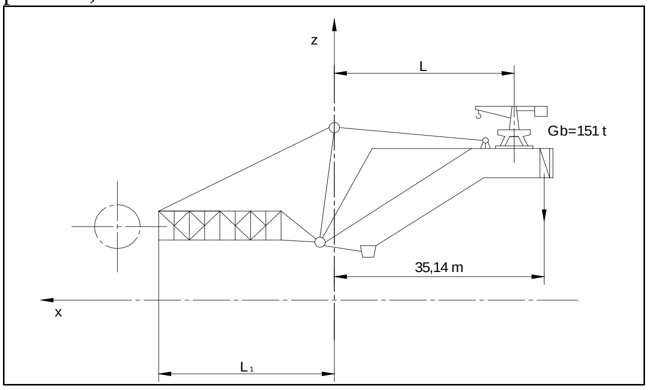


Figure 9. Third phase of measuring;

3.2.4 Fourth measuring phase

The arrow of rotor, image 10, is located in upper position (angle of lean relative at horizontal ≈ 18°) without etalon – load.

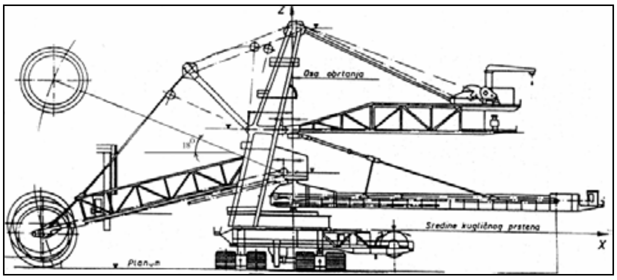


Figure 10. Fourth measuring phase;

3.2.5 Order of lifting supporters

Order of supporters (measuring spots) of upper construction is shown on fig. 11. Hydraulic cylinders in supporters A_1 and A_2 are hydraulic connected, which is secured for their synchronized work.

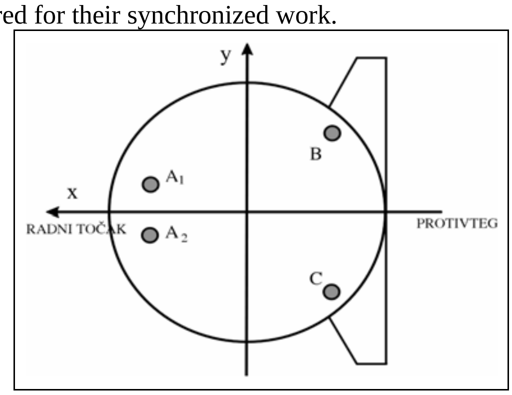


Figure 11. The slant of supporters of upper construction (measuring spots)

First are lifted the supports towards counterweight, image 11, and to supporter C for 3mm, then the supporter B for 3 mm. Both of those cases the security screw nut must be tighten, so except the elements of hydrostatic system (hydraulic oil, ports, connectors) the load is carried also and safety screw nut. Then, they lift the supporters beneath the arrow of rotor (A_1 and A_2) for 3mm.

Implementation of this procedure comes to lifting of upper construction for ≈ 20 mm, thereby providing totally relief of radial-axial bearing. Thereby, after the last cycles od lifting, there is no tighten of security screw nuts which is secured that whole weight of construction are carried out by hydraulic cylinder. In that position the values of pressure in hydraulic cylinder has been read (first measuring chain) and intensity of supporter's reaction obtained using different measuring chain. The received data are presenting the "zero measuring condition". To eliminate the effect of mistake which occurs in first measuring chain (friction between piston and cylinder) in all phases of measuring, the next procedure is carried out:

- Lifting the supporters in order C, B and A (A_1 and A_2), for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);
- Lowering the supporters in order A (A_1 and A_2), B and C, for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);
- Lifting the supporters in order B, A (A_1 and A_2) and C, for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);
- Lowering the supporters in order C, A (A_1 and A_2) and B, for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);
- Lifting the supporters in order A (A_1 and A_2), C and B for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);
- Lowering the supporters in order B, C and A (A_1 and A_2), for 2mm, with reading the measuring of pressure (first measuring chain) in hydraulic cylinder and intensity of reaction of supporters (Second measuring chain);

3.3 Measuring of weight and position of brunt of upper construction of bucket-wheel excavator

With secured the unnecessary conditions for measuring performing, the loads of supporting dots are caused exclusively by the weight of the upper construction, 12.

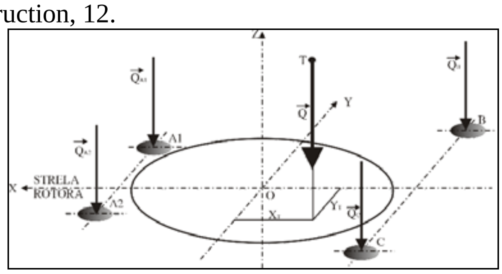


Figure 12. Scheme for determination of the weight and position of upper construction brunt

Considering the fact that the intensities of loads of supporters of the upper construction are equal to intensities of adequate reactions who are measured, their Wight is calculated based on expression:

$$Q = Q_{A1} + Q_{A2} + Q_B + Q_C,$$

In which are Q_{A1}, Q_{A2}, Q_B i Q_C loads of supporting dots.

The position of projection of the upper construction brunt to a reference flat line (the flat line of radial-axial bearing) is determined by Varin's theorem,

$$X_T = (\Sigma\ Qi \times Xi) / Q,$$
$$Y_T = (\Sigma\ Qi \times Yi) / Q,$$

whereby the coordinates of supporters of the upper construction (X_i and Y_i) are determined by geodetic measurement.

4. MEASURING SYSTEM AND EQUIPMENT

Before start measuring, the machine must be in position which is prescribed by the manufacturer ("the remount position"). After that in the space between adequate supporters on lower and upper construction are set the hydraulic cylinder with measuring cells. The look of the measuring place is shown on fig. 13.

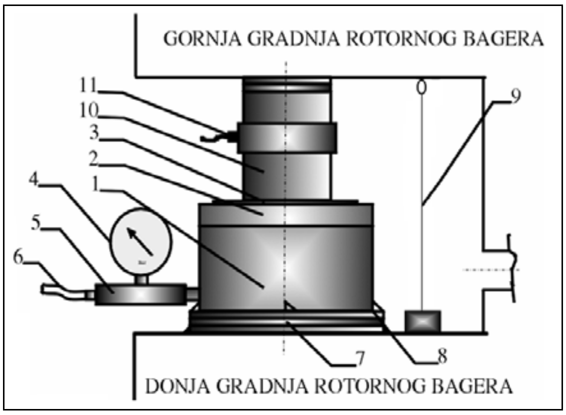


Figure 13. Measuring place; 1 – hydraulic cylinder; 2 – safety screw nut; 3 – piston of the hydraulic cylinder; 4 – manometer; 5 special rail; 6 – hose; 7 compensation metal sheets; 8 limiters; 9 – sensor of moving; 10 – measuring cell; 11 – electric connection;

4.1 The hydraulic cylinder

When both measured chains, hydraulic cylinder is used as lifters of the upper construction. Simultaneously, in the first measuring chain (hydraulic) they're used also as pressure giver, which value is read on manometer.

For performing the measuring there are used the hydraulic cylinders: Enerpac CLP – 5002, image 14, with maximal force of repression 5000 kN. The basics technical characteristics are in table 4.1.

Before starting measuring, must be proceeded calibration of hydraulic cylinders.

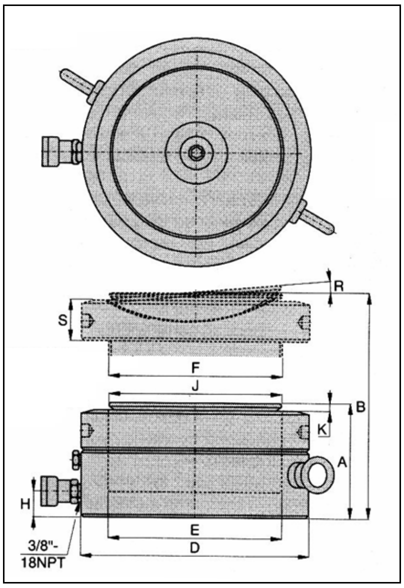


Figure 14. Hydraulic cylinder CLP – 5002;

Table 4.1

Steps (mm)	45
Force (kN)	5114
Effective area (cm²)	730,6
Volume of cylinder (cm³)	3287
A (mm)	192
B (mm)	237
D (mm)	400
E (mm)	305,0
F (mm)	Tr 305 x 6
H (mm)	48
J (mm)	290
K (mm)	10
R	3⁰
S (mm)	62
Masa (kg)	150

4.2 Safety screw nut

The task for the safety screw nut, image 15, is that stop the unwanted return movement of the piston and to enable partially relief of elements of hydrostatic system. They during the lifting process of the upper construction "follow" the movement of the piston, until is achieved completely relief of radial-axial bearing.

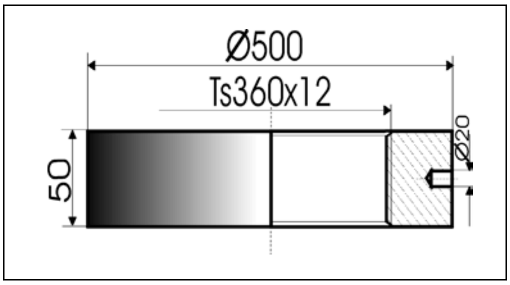


Figure 15. Safety screw nut;

After relief of radial-axial bearing, the screw nut is out of function, and the maximum value of axial gap between them and body of hydraulic cylinder is≈ 2mm, fig. 16. On that way it's stopped if in case of failure of some component of hydrostatic system loss occurs of statistic stability of machine.

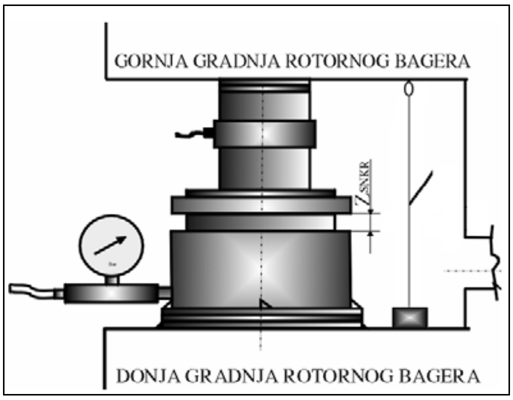


Figure 16. Position of safety screw nut after relief of radial-axial bearing;

4.3 The manometer

Every hydraulic cylinder is equipped with calibrated manometer. These manometers must comply further requests:

- Accuracy class– 1;
- Measuring range – till 600 bar;
- Dividing scale– 1 ... 5 bar;
- Performed the safety from the hydraulic attacks;

4.4 The safety screw nut

For the purpose of measuring, it's developed a special screw nut, fig. 17, with gasket ring which prevents uncontrolled oil motion.

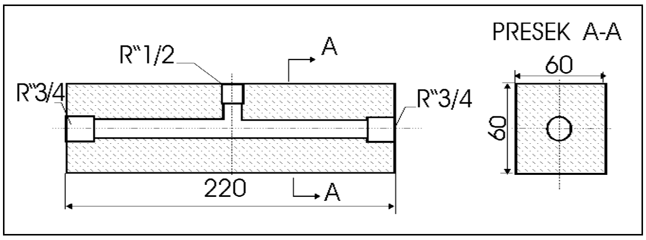


Figure 17. Safety screw nut;

4.5 The hydraulic hose

Linkage of components of hydraulic system is carried out with corresponding hoses, working pressure 700 bars.

4.6 Compenzation of meatl sheets

Hydraulic cylinders are placed at metal sheets edge, image 13, which are mutually and with support on lower construction welded. Metal sheet on which are placed the hydraulic cylinder must be immaculately clean and degreased.

4.7 The limiter

To stop the uncontrolled horizontal moving of hydraulic cylinder movement at upper compensation metal sheets are welded the corresponding limiters, fig. 18.

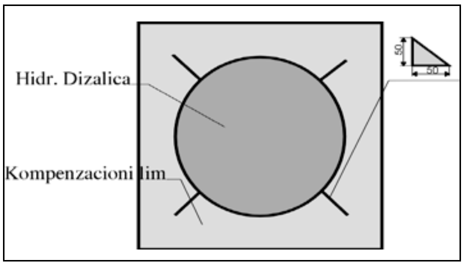


Figure 18. Distribution of limiters;

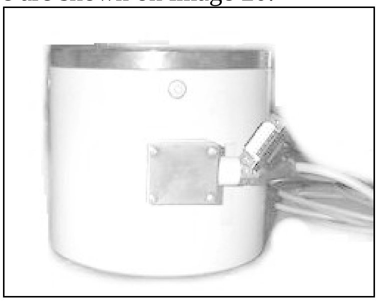
4.8 Moving sensor

If is the lifting of the upper construction supported by a computer then it's used the sensor of moving, as shown on image 19. His body is places directly by hydraulic cylinder, and a rope is tied for upper construction. Throw of the rope is 500 mm.

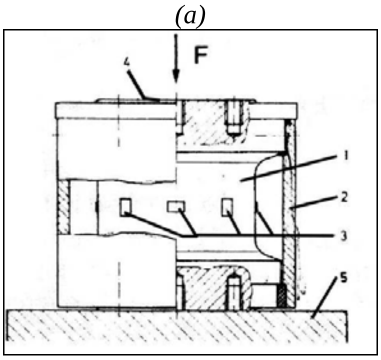
Figure 19. Sensor of moving;

When the upper construction is lifted then it's used the Manuel controller hydraulic aggregate, reading of movement is proceeded on a special constructed ruler, 4.9 The force transuder

The base of the second (electric) measuring system is force transude (measuring cell) HBM – C6. Her form and structure are shown on image 20.



(a)



(b)

Figure 20. Measuring cell; (a) – prospect; (b) – structure; 1 – body (measuring cylinder); 2 – safety armor; 3 – measuring tapes; 4 – editorial of the loads; 5 – base;

Shape, dimensions and construction of measuring cell must fulfill further conditions:

- Linear addiction deformation from intensity of loads with uniform distribution of voltage
- As small as possible hysteresis;
- As small as possible sensitivity at temperature conditions;
- Possibility of setting in area of relatively small dimensions;

To achieve completely and centrically fitting of the upper construction to the measuring cell, also as fitting the measuring cell to the lower construction there are used special designed elements – editorial for loads and bases.

The force transudes shown on image 4.8 enables and measuring in time domain. That means that it's possible to measure the intensity of reaction of supporters of the upper construction during the machine's work, if that isn't limited by her conception.

4.10 Hydraulic aggregate

For lifting of the upgrades, there are used:

- Hydraulic aggregate with manual controls;
- Hydraulic aggregate with computer controls;

Hydraulic aggregate of maximum working pressure of 630 bar, flows 21 liters/min, has been placed on top platform or onto formation. The way of connecting aggregate with hydraulic cylinder in supports of the upper construction is shown on fig. 21.

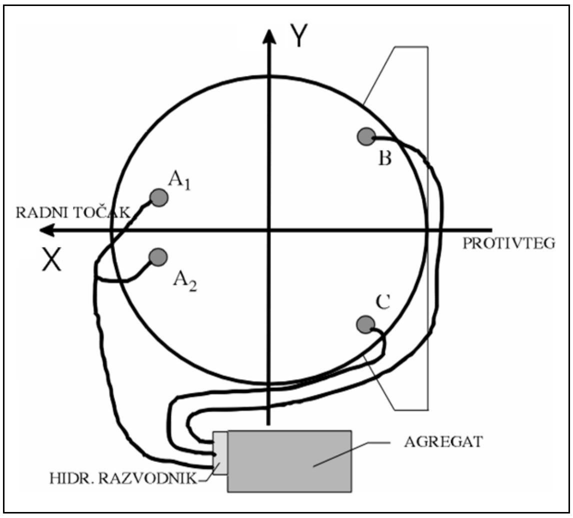


Figure 21.

Computer controlled aggregate (maximal working pressure of 700 bar) with all elements of system for lifting, is shown on fig. 22. Functional relations of some elements of the system are shown on fig. 23. Considered system enable synchronously lifting of all supporters of the upper construction with at the same time following of imbalance. If the difference of moving some supporters exceeds a pre – defining value, system is going to shut down automatically.

Figure 22. Elements of the system for synchronously lifting of the upper construction;

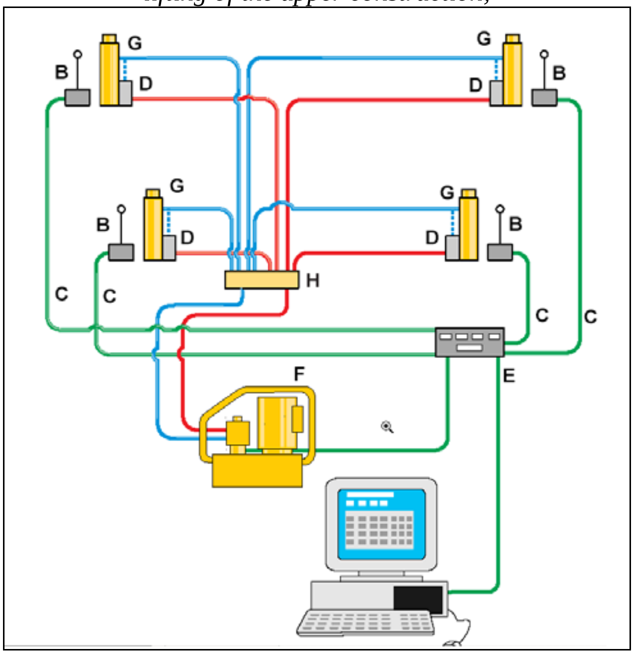


Figure 23. Functional scheme of system for synchronously lifting; A – manual unit; B – sensor of moving; C – electric wire; D – hose; E – junction box; F – pump; G – hydraulic cylinder; H – distributor;

4.11 Measuring system and processing of the signals

In base, measuring system is: measuring converter of force (measuring cell) and electric part, fig. 24. The observed system, with weight also impact: vector $\vec{D}$ which represent adverse effects of reception and transfer of outside loads, the vector of parasite loads $\vec{P}$ and vector $\vec{S}$ which present various outside effects.

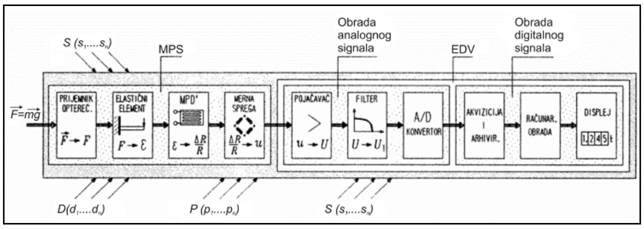


Figure 24. Functional scheme of measuring system [5]

Body of measuring cells are deformities under the effect load caused by weight of the upper construction. Deformation is transferred to the measuring tapes which cause the balance disorder of the Vat's Bridge and appearance of the signal at his exit. Mentioned signal is relatively weak, of the order mV, which is necessary to perform his amplification. That's achieved with help of operational amplifier in form of the integrated circuits.

Basic request which must be fulfilled by amplifier are:

- Huge entrance resistance;
- Steadily amplifier;
- Expressed linearity;
- Low level of woods;
- Weak sensitivity of amplifier and zero on temperature;

The echo and eventually annoyance are removed with use of electronic filters which are posted on the net part (removing the annoyances which are coming from power), on the entrance of the measuring amplifier (filter for frequent selection of signal) and on entrance to A/D convertor (elimination of alternating components of signals).

Transformation of analogue into digital signal is performed in A/D convertor. There, in basic down to quantifications of signals in frequent domain. Digital signal is much more suitable than analogue, because: less sensitivity to the outside factors and much easy processing.

Measuring, which short review is shown in 6.0, are performed using of the measured amplifier HBM MGC+, image 25, supported by note book computer. Shown device enables measuring at the same time by 128 independent channels, which are equipped by independent amplifiers and intern CPUs. Control and work management of universal measuring amplifier, acquisition and numerical and graphical representation of results are achieved with appropriate software.

Figure 25. Universal measuring amplifier MGC+;

5. WEIGHT MEASURING AND DETERMINATION OF BRUNTS POSITION OF THE UPPER 5. CONSTRUCTION OF THE BUCKET-WHEEL EXCAVATOR KRUPP SchRs 1760

To achieve the wanted accuracy of measuring it's necessary to rigorously proceed next procedure which includes:

- Preparation of the formation on which are going to proceed the measuring;
- Preparation and placing of the excavator in measuring position;
- Placing the measuring equipment;
- Performing measuring;

5.1 Preparation of the field

Before placing of the excavator, the formation must be settlement whereby the maximum allowed slope is 1:300.

5.2 Preparation and placing of the excavator in measuring position

Preparation of the excavator consider:

- Dismantling of protection of the geared wreath in area of the hooks – catchers, also and gaskets of rolling ball relation and hooks catchers;
- Prevention of the rolling of the upper construction, which is achieved by activating of adequate brakes;
- Checking the gap between geared wreath and small gears of drive rolling construction;
- Placing the breaks of caterpillar's movement in considering position;
- Shutting down the high voltage power of the electric energy;

Measuring are performed in following position of machine, image 26:

- Deponent lane is rolled in angle of 100° in relative to ax of console of the counterweight;
- The arrow of rotor and the arrow of the personnel cabin is in set formation position;
- The reloading device is set in final position;
- Elimination of conditions of the reloading device that is achieved by setting of the support at distance of ~11200 mm from the ax of radial-axial bearing, fig. 27.

Figure 26. The excavator in his measuring position;

Figure 27. The support of reloaded device;

5.3 Placing of the measuring equipment

In measuring dots, A, B, and C, fig. 28, there are placed each by two hydraulic attached hydraulic cylinder (Enerpac CLP – 5002, maximal force of 5000 kN) with measured mounting boxes (HBM – C6, measuring range 0 do 5000 kN), image 29. and 30. Synchronized lifting of the upper construction is achieved with computer's supported system, fig. 31.

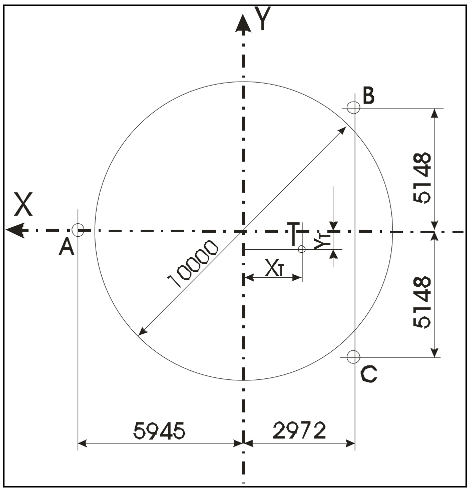
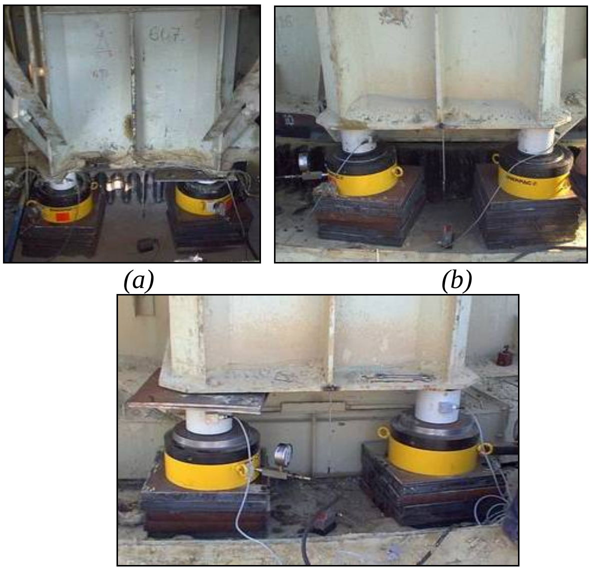


Figure 28. Schedule of measuring places;



(c)

Figure 29. The look of measuring spot A (a), B (b) and C (c);

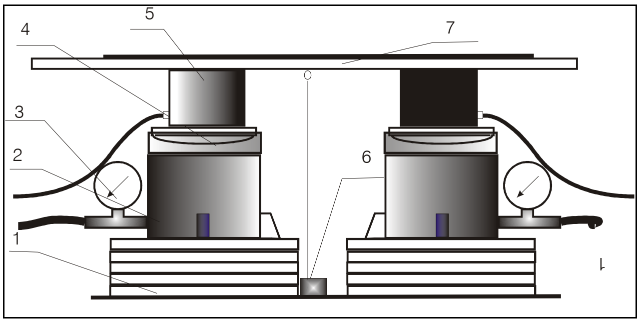


Figure 30. Structure scheme of one measuring spot: 1 – metal sheet (package); 2 – hydraulic cylinder; 3 – manometer; 4 – calotte; 5 – measured mounting boxes; 6 – movement sensor; 7 – upper construction;

Figure 31. System for synchronously lifting and measure amplifier;

5.4 Measuring procedure

During measuring performance, the arrow of rotor and the arrow of operator cabin of the excavator is placed in lower position, thereby is the lover edge of rotor is placed to a ≈ 500 mm from formation.

The first series of measuring is performed with control weights with total mass of 13.6 t, which are hanged for the first frame of the rotor arrow (viewed to an articular relation of the fifth arrow of rotor), fig. 32. Relief of radial-axial bearing achieved by synchronously lifting of the upper construction (in total of 15 mm), with tighten of safety screws at pistons of hydraulic cylinder. After that the visual control of relieved rolling bodies of radial-axial bearing is carried out (fig. 33.). That level is accepted for referent flat line of measuring. After reading of intensity of loads in support dots (≈ 100 values) A, B and C, there's performed the synchronously lifting down the supporting dots for 2 mm from the level of referent flat line. After performed measuring, the upper construction is lifted down to the upper construction.

Figure 32. Position of the control weights;

Figure 33. Visual control of relief of the rolling bodies of the radial-axial bearing;

After removing of the control weights, there are performed the second series of measuring by the same procedure.

5.5 The results of measuring

The results of first and second series of measuring. They are given in tables 5.1 and 5.2, respectively.

Table 5.1: (with control weight):

Opterećenja oslonaca [kN]			Ukupna težina [kN]	X_T	Y_T
F_A	F_B	F_C	*kN*	*m*	*m*
7111.3	4136.3	4527.7	15775.3	1.05	-0.13
7093.1	4147.4	4535.3	15775.8	1.04	-0.13
7081.6	4152.7	4542.2	15776.5	1.03	-0.13
7080.6	4153.0	4544.2	15777.7	1.03	-0.13
7104.4	4138.1	4532.7	15775.2	1.04	-0.13
7096.0	4141.8	4537.5	15775.4	1.04	-0.13
7085.4	4148.0	4543.9	15777.3	1.03	-0.13
7082.7	4148.7	4544.5	15775.9	1.03	-0.13
7086.5	4147.8	4540.5	15774.8	1.03	-0.13
7093.3	4145.6	4536.3	15775.1	1.04	-0.13
7110.6	4138.1	4527.6	15776.4	1.05	-0.13
7124.5	4129.4	4520.9	15774.9	1.06	-0.13
7129.9	4125.4	4518.7	15774.1	1.06	-0.13
Srednje vrednosti			**Q_1=15776.0**	**X_T = 1.05**	**Y_T = -0.13**

Table 5.2: (without control weight):

Opterećenja oslonaca [kN]			Ukupna težina [kN]	X_T	Y_T
F_A	F_B	F_C	kN	m	m
6397.0	4414.5	4806.8	15618.3	0.68	-0.13
6378.6	4426.4	4817.8	15622.7	0.67	-0.13
6375.4	4429.0	4820.9	15625.3	0.67	-0.13
6379.1	4425.3	4815.9	15620.3	0.67	-0.13
6412.5	4402.2	4795.6	15610.3	0.69	-0.13
6423.8	4396.1	4789.5	15609.5	0.70	-0.13
6437.6	4387.1	4781.8	15606.6	0.71	-0.13
6439.8	4386.1	4781.1	15607.0	0.71	-0.13
6432.3	4390.0	4784.1	15606.4	0.70	-0.13
6415.0	4401.6	4795.4	15612.0	0.69	-0.13
6404.4	4408.6	4802.4	15615.4	0.69	-0.13
6394.5	4415.6	4808.0	15618.2	0.68	-0.13
6380.2	4424.9	4815.6	15620.6	0.67	-0.13
Srednje vrednosti			**Q_2 = 15614.0**	**X_T = 0.69**	**Y_T = -0.13**

6. CONCLUSION

The final results of measuring, weighing, of the upper rolling construction of the bucket-wheel excavator KRUPP SchRs 1760 are:

- Weight of the upper rolling construction is: Q=1561,4 t
- Projection of the weight is: Xt=690 mm and Yt=-130 mm

And shows that these results of Xt and Yt in the limits of permissible $^+$-Dk/4 i.e. $^+$-2500 mm which makes the statistic stability of the rolling upper construction of the bucket-wheel excavator in the zone of stability and there is no fear from rolling and there is no need for correction of weight in counterweight of the excavator.

ACKNOWLEDGEMENT

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