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DIJAGNOSTIKA STANJA I PONAŠANJA ČELIČNE KONSTRUKCIJE ROTORNIH BAGERA

STRUCTURAL DIAGNOSTICS AND BEHAVIOUR OF BUCKET WHEEL EXCAVATOR

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Ključne reči

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- čelična konstrukcija
- zamor

Keywords

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- maintenance
- bucket wheel excavator
- steel structures
- fatigue

Izvod

Površinski kopovi u Srbiji su osnova proizvodnje uglja, što opravdava usmerenje aktivnosti na neprekidni rad i održavanje mašina i uređaja za površinsku eksploataciju. Složenost konstrukcije rotornih bagera i drugih rudarskih mašina (odlagača, samohodnih transportera), njihova visoka cena, i visoki troškovi otkaza i održavanja, ukazuju na potrebu istraživanja i razvoja efikasnog sistema za dijagnostiku.

U ovom radu su definisani postupak i razvoj integralnog modela sistema za dijagnostiku stanja i ponašanja čelične konstrukcije rudarskih mašina, što omogućava donošenje odluke o daljim akcijama vezanim za njihov rad (praćenje stanja, nastavak rada bez intervencija, revitalizacija, modernizacija, rekonstrukcija ili otpis).

Rezultat ovih istraživanja je sistem procedura i njihovih međusobnih odnosa u cilju dobijanja podataka koji definišu stanje rudarske opreme i način daljeg delovanja.

Abstract

Surface mines in Serbia are the basis of coal production, justifying to focus the activities on continuous operation and maintenance of machinery and equipment for surface mining. Structural complexity of bucket wheel excavators and other mining machinery (spreaders, belt wagons), their high prices and high costs of failures and maintenance indicate the need to research and develop an efficient diagnostics system.

The article defines the methods and development of the model of an integrated system for state diagnostics and behaviour of mining machine steel structures, enabling to decide on further actions for their operation (state monitoring, to continue operation without intervention, retrofit, updating, redesign or amortisation).

The result of this research is a system of procedures and their mutual relations with the aim to obtain data on defining the mining equipment state and mode of further treatment.

UVOD

Potreba efikasnosti i smanjenja troškova na površinskim kopovima doveli su poslednjih godina do novih pristupa održavanju mašina i opreme. To su, pre svega, pristupi održavanja koji predviđaju i predupređuju događaje /2/. Na ovaj način se može direktno uticati na vek rotornog bagera, ali i na performanse bagera, koje se održavaju u projektovanom opsegu ili se u nekim segmentima i poboljšavaju.

Postupak se zasniva, s jedne strane, na bitnom unapređenju dijagnostičkih uređaja (velika preciznost, prikupljanje

INTRODUCTION

The need for efficient and reduced costs on surface mining has recently opened new approaches to machinery and equipment maintenance. Primarily, these approaches enable to predict and proact the events, /2/. In this way it is possible to effect directly on bucket wheel excavator life, and also its performance, saving in design limits or, in some segments, even improvement.

The method is based, on one hand, on substantial improvement of diagnostic devices (high precision, collect ogromne količine podataka, jednostavan prenos podataka, uz pojeftinjenje i olakšanu primenu), što olakšava tehničku dijagnostiku, a sa druge strane na novoj generaciji standarda, koji u nekim oblastima napuštaju klasična shvatanja, čak i u nacionalnim propisima.

Na kraju, ali uz bitan uticaj, bilo je značajno u postupak uneti iskustvo sakupljeno sa rudarskim mašinama za površinsku eksploataciju u pogledu projektovanja, eksploatacije, dijagnostike, kao i sistema održavanja, /1, 8, 9/.

CILJEVI

Da bi se došlo do valjanih kriterijuma za procenu neophodnosti zamene pojedinih delova opreme ili konstrukcije, neizbežna su obimna dijagnostička ispitivanja. Važan deo ovih ispitivanja se odvija u *on-line* i *off-line* režimu. Ove metode omogućavaju bolji uvid u stanje pojedinih uređaja, a time njihovu bolju iskorišćenost. Ciljevi primene dijagnostičkih metoda, /3/, su:
– sprečiti ponovljene otkaze mašina,
– smanjite troškove održavanja,
– povećati vreme ispravnog rada mašine (pouzdanost),
– produžiti vek trajanja mašina,
– optimizovati efikasnost opreme u radu,
– unaprediti proces planiranja,
– omogućiti uspešno funkcionisanje održavanja i proizvodnje.

RAZVIJENI METODOLOŠKI PRISTUP DIJAGNOSTICI ROTORNOG BAGERA

Poznavanje stanja i ponašanja rotornog bagera i pridružene opreme u svakom trenutku je osnovni cilj dijagnostike. Na taj način mogu da se osiguravaju optimalni parametri funkcionisanja sistema, ali i da se predvideti pogodan rok do eventualne revitalizacije i rekonstrukcije, da bi dalji rad bio siguran i ekonomičan. Ovakvim pristupom se definišu osnovni i posebni zahtevi za pouzdano i trajno korišćenje rotornog bagera.

Različit je značaj dijagnostike postojeće konstrukcije, koja je već ostvarila određeni vek u radnim uslovima i projekta nove konstrukcije. Pouzdani projekt nove konstrukcije se ostvaruje analizom numeričkih pretpostavki i odabranog standarda za projektovanje i eksperimentalnu verifikaciju proračuna, a na osnovu iskustva u radu sličnih konstrukcija, sl. 1. Eksperimentalna verifikacija treba da otkloni nepoznanice koje postoje u standardima, a prvenstveno se misli na opterećenja koja su pretpostavljena i predstavljaju „slabu“ tačku proračuna. Eksperimentalnom verifikacijom numeričkih pretpostavki može se sagledati stanje i ponašanje rudarske mašine najpribližnije stvarnom, a to je i najpouzdaniji podatak za projektovanje nove mašine.

Dijagnostika novih mašina preuzima rezultate i iskustva dijagnostike postojećih, po mogućstvu ih redukuje na najmanju meru potrebnu da se vidi da li se nova konstrukcija ponaša prema predviđenom proračunu.

Tehnički uslovi dijagnostike ponašanja i stanja opreme su definisani u algoritmu primene, sl. 1.

Ovakvim pristupom se usmeravaju saznanja iz različitih oblasti ka jednom, pojednostavljenom cilju: da se sa što manje parametara utvrdi ponašanje konstrukcija, odnosno, da li je njen odgovor na opterećenja u skladu sa predviđa

ing enormous amount of data, simple data transfer followed by low price and easy application), enabling to simplify technical diagnostics, and on the other hand, on a new generation of technical standards, which in some areas have abandoned classical concepts, even national regulations.

The last, but not the least, it was important to implement into the procedure the experience gathered with mining machinery for surface mining in the area of design, operation, diagnostics, as well as system maintenance, /1, 8, 9/.

GOALS

To obtain relevant criteria for assessing the necessity to replace some parts of equipment or structure, extensive diagnostics tests are inevitable. An important part of these test is in *on-* and *off-line* mode. These methods enable better insight into the state of individual devices, and their better utilization. The objectives of implementing diagnostic methods are, /3/:
– prevent repeated failures of machines,
– reduce maintenance cost,
– increase machine correct service period (reliability),
– extend the operating life of machines,
– optimise the efficiency of equipment in service,
– improve the planning process,
– ensure successful operation, maintenance and production.

DEVELOPED METODOLOGY APPROACH OF BUCKET WHEEL EXCAVATOR DIAGNOSTICS

Recognition of bucket wheel excavator and the associated equipment state at each moment is the major diagnostics goal. In this way, optimal functional system parameters can be assured, but also it is possible to predict convenient term for eventual retrofit and redesign, enabling further safe and economical operation. This approach allows to define basic and special requirements for reliable and continuous bucket wheel excavator service.

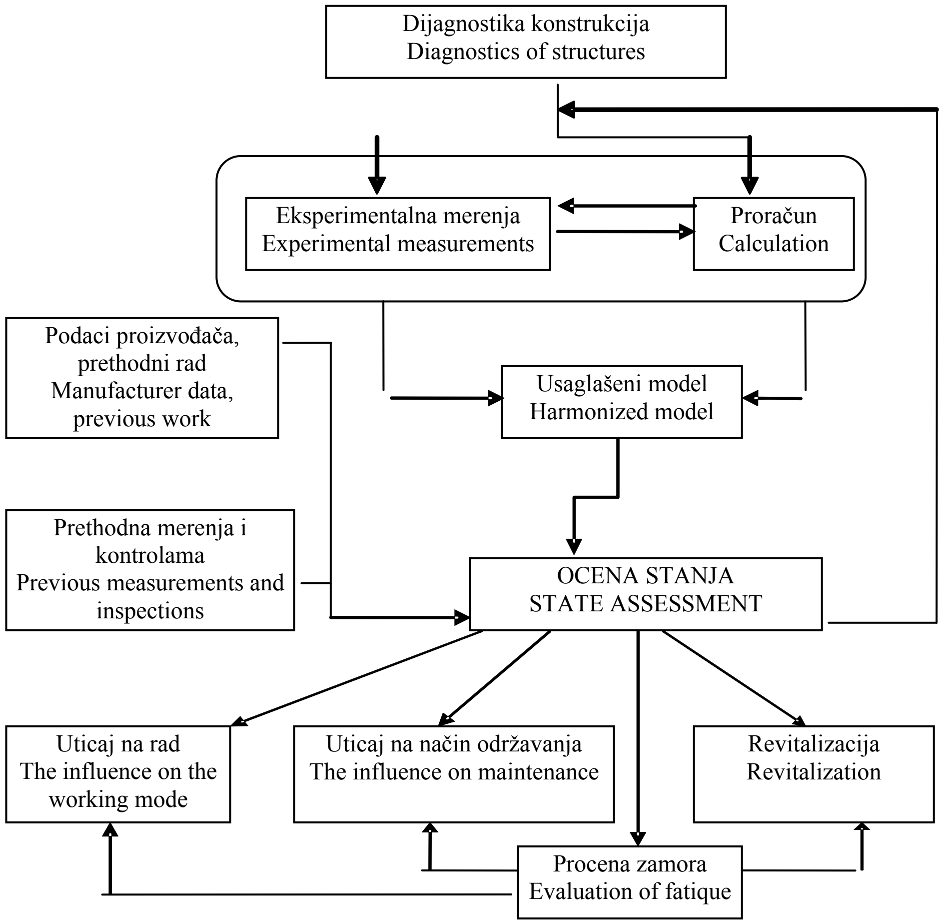
There is a difference between the diagnostics of existing structures that had already performed a certain life in service conditions and new structural design. Reliable design of a new structure is realised by analysis of numerical assumptions and selected standards for design and experimental verification of calculation, and based on service experience with similar structures, Fig. 1. Experimental verification should eliminate all uncertainties existing in the standards, primarily having in mind accepted loads that represent a “weak” point in calculation. Experimental verification of numerical assumptions allows an insight in the state and behaviour of mining equipment the closest to real, as a most reliable data for new machine element design.

Diagnostics of new machines takeover the results and experiences of realized diagnostics, possibly by reducing them to minimum measures, necessary to see if new structures behaviour corresponds to predicted calculations.

Technical requirements of equipment behaviour and state diagnostics are given in application algorithm (Fig. 1).

By such an approach the existing knowledge in various fields is directed to a single, simplified goal: with minimum parameters to assess structural behaviour, that is whether its load “feed back” is in accordance with the predicted calcu njem proračuna. To je i najvažniji doprinos u pristupu razmatranoj materiji, koji se može dalje razvijati u više pravaca. Ne smeju se zanemariti ni podaci o tome šta je konstrukcija u prethodnom radu preživela.

lation. This is the most important contribution in the approach to the considered matter which can be developed in several directions. Also, data on what the structure had survived in the previous service must not be neglected.



Slika 1. Dijagnostika stanja konstrukcija
Figure 1. Diagnostics of structural state.

Dostignuti razvoj merne opreme, niska cena i pogodnost prenosa podataka dovode u pitanje koristi od ogromnog broja podataka. Ovo je važno ako se konstrukcija ne ponaša kako je predviđeno u projektu, do čega može doći, na primer, zbog neprikladnog projektnog rešenja, promene radnih uslova ili zamora materijala.

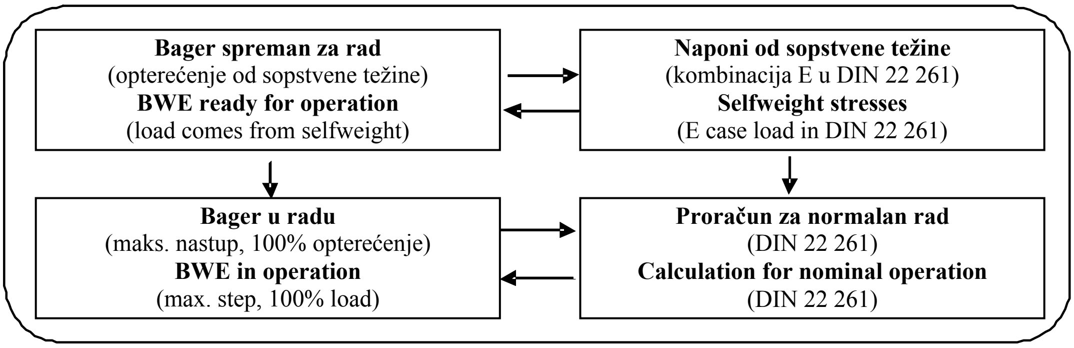
Pri ispitivanju sistema rotornog bagera postoje razlike u ispitivanju noseće čelične konstrukcije i prateće funkcionalne opreme. Kod noseće konstrukcije prevashodan cilj je sigurnost bagera, dok ispitivanja uređaja opreme daju podatke o stanju uređaja, koji su presudni za ocenu efikasnosti u radu.

Na sl. 2 dat je prikaz usaglašavanja eksperimenta i proračuna prema standardu DIN 22261. Razvijeni dijagnostički tok sa sl. 1 predviđa ocenu stanja i posledice na osnovu usaglašenog modela. Nakon toga sledi analiza zamora koja definiše aktivnosti na dalje tretiranje konstrukcije. Ovakav pristup predviđa korekciju ulaznih vrednosti za proračun na bazi ispitivanja, što odgovara i novom konceptu proračuna zamora materijala i preporukama o korišćenju realnih vrednosti opterećenja.

Achieved development of measuring instruments, low cost and data transfer convenience open the question of benefits of enormous amount of data. This is important if the structure does not behave as predicted in design, what can happen, for example, due to improper design solution, operating condition changes or material fatigue.

There are differences in testing the bucket wheel excavator system, related to supporting steel structure and associated functional equipment. In the supporting structure, the basic goal is excavator safety, while the tests on equipment devices produce data about the state, important for system service efficiency.

Figure 2 shows the matching of the experiment and according calculation procedures. The developed diagnoses flow chart from Fig. 1 is based on state evaluation and on the fatigue analysis matching model. The developed approach anticipates the correction of calculation input values based on tests, corresponding also to the new concept of material fatigue calculation and to recommendations of real loading value application.



Slika 2. Usaglašavanje eksperimenta i proračuna na primeru DIN 22 261
Figure 2. Matching of experiment and calculation in the example of DIN 22 261.

Postupak dijagnostike je iterativan, odnosno, „autoedukativan“ ili „autokorektivan“. To znači da se iz analize rezultata merenja na jednoj mašini može dobiti poboljšani model za druge, konstrukcijski slične mašine. Kao rezultat dijagnostike stanja i ponašanja neke konstrukcije može se dobiti predlog zahtevanih mera. To može direktno uticati na optimizaciju održavanja mašina i opreme na kopovima i na revitalizaciju, /10/.

Poznavanje stanja konstrukcije omogućava i analizu zamora. Kod velikih rudarskih mašina, sa uglavnom statički određenim elementima, ima manje prostora za eksplicitnu primenu pretpostavki zamora nego u nekim drugim slučajevima, ali se sa dobijenim pretpostavkama o zamoru može uticati na tehnološke parametre rada bagera, na način održavanja ili na eventualnu odluku o revitalizaciji.

PRIMER

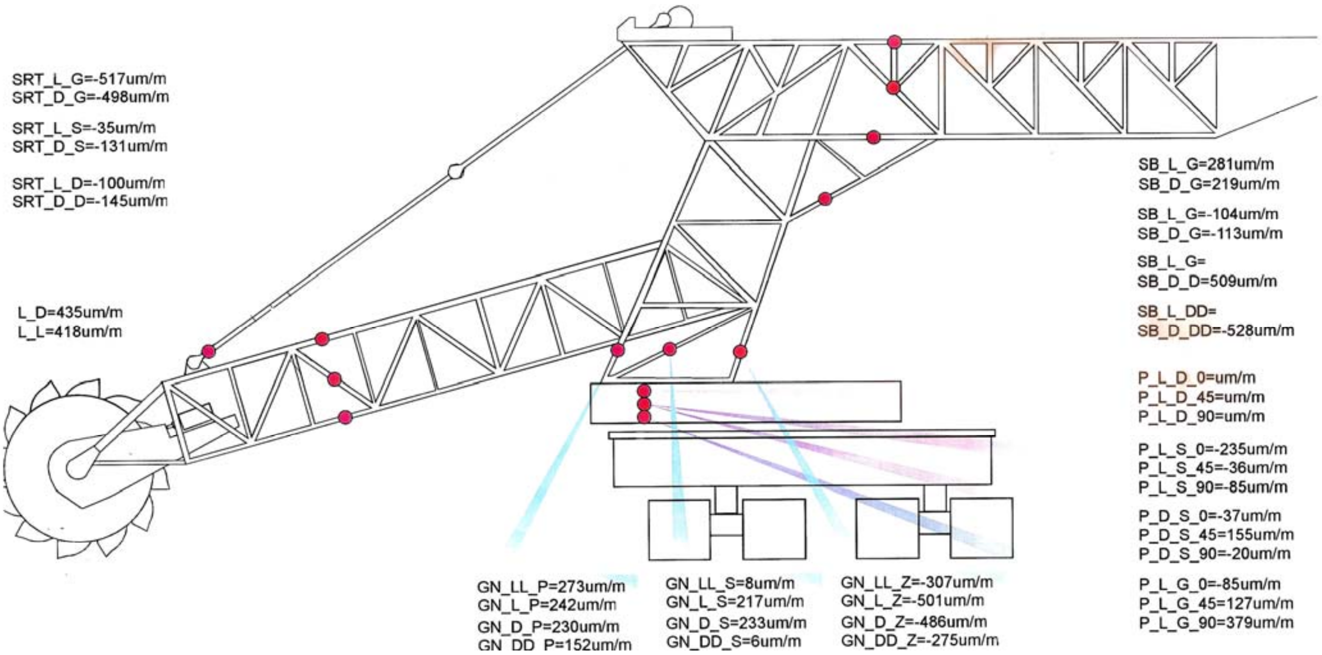
Rotorni bager SRs 1301×24/2,5 (400 kW)+V, fabr. br. 1513, (TAKRAF, Istočna Nemačka), proizveden je 1982. godine. Do 2006. je radio na otkopavanju uglja na površinskom kopu Nohten.

The diagnostic process is iterative, or “self educative” or “self-correcting”. It means that from the analysis of measurement results made for one machine an improved model for other machines of similar design can be obtained. As a result of state and behaviour diagnostics of some structure, a proposal of required measures can be obtained. This may directly affect optimising machines and equipment maintenance and retrofit at surface mines, /10/.

Knowing the state of structures enables also fatigue analysis. On large mining machines, with mostly statically determined elements, there is less space for explicit application of fatigue assumptions than it is in some other cases, but certainly defined fatigue assumptions allow to affect the technological parameters of excavator operation, the way of maintenance or eventual decision making for the retrofit.

CASE STUDY

Bucket wheel excavator SRs 1301×24/2.5 (400 kW)+V, No. 1513 (TAKRAF, East Germany), has been produced in 1982. Until 2006, it has operated on digging coal at the Nochten surface mine.



Slika 3. Obeležavanje mernih mesta
Figure 3. Designation of measuring locations.

Ovaj tip bagera predstavlja osnovnu mehanizaciju za otkop uglja i na ostala tri površinska kopa u Vatenfal Jurop Majning. Demontažu i transport su izvršile nemačke firme koje je angažovao Takraf, a pod nadzorom Kolubare Metal, koja je izvršila delimičnu revitalizaciju i montažu bagera na montažnom placu Zeoke.

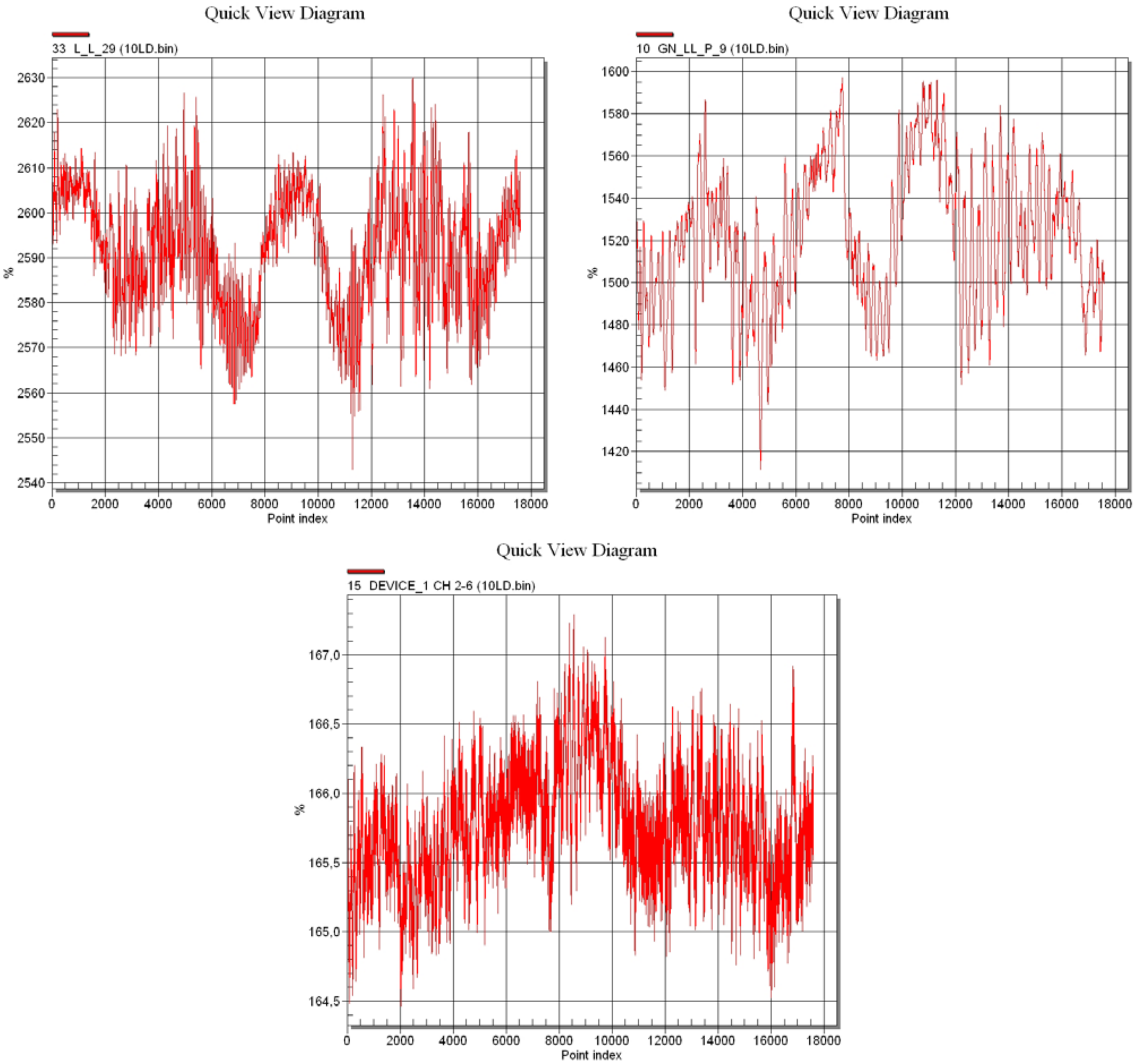
Izveden je pilot projekt, /7/, da se pokaže mogućnost postepenog prelaska na održavanje po stanju i da u saradnji sa korisnikom pokažu prednosti ovakvog održavanja. Za ispitivanje su postavljene 32 merne trake (HBM, Nemačka) za merenje deformacija u konstrukciji (sl. 3), i izabrana 32 merna mesta za vibrodijagnostiku. Bežičnim prenosom skupljeni podaci se šalju u prijemni centar (računar) koji se nalazi u RB Kolubara i Kolubara Metal.

Označena su mesta mernih traka sa sl. 3: GN-stub; SB-protivteg; ST-pogon rotora; L-lamela, P-platforma; L-levo; R-desno; G-gore, D-dole.

This type of excavator is also the basic machinery at other three surface mines of Vattenfall Europe Mining. Disassembly and transport are carried out by German companies, engaged by Takraf, under the supervision of Kolubara Metal, which has carried out a partial retrofit and assembly of excavator on the Zeoke erection site.

A pilot project, /7/, is performed to show the possibility of gradual transition to the maintenance based on state and in cooperation with the user to demonstrate the advantages of this method. Testing included 32 strain gauges (HBM, Germany) for measuring strains on the structure (Fig. 3), and 32 points are selected for vibration diagnostics. Wireless transmission of collected data is done via the receiving centre (PC) located in RB Kolubara and in Kolubara Metal.

Strain gauge locations are indicated in Fig. 3: GN-tower; SB-counterweight; ST-bucket wheel boom; L-lamella; P-platform; L-left; R-right; G-up; D-down.



Slika 4. Zapisi sa merenja pod opterećenjem
Figure 4. Records from measurements under loading.

Proračun noseće konstrukcije gornje gradnje

Proračun nosećih delova konstrukcije kako za originalnu mašinu, tako i za revitalizovanu (sa oznakom SRs 1301) uradio je TAKRAF, Lauhamer, prema Istočnonemačkom standardu TGL. Proračun revitalizovane mašine urađen je samo za gornju strukturu.

Najveća razlika između stare i revitalizovane mašine se javila zbog povećanja težine elektro opreme i to u streli balasta (frekventna regulacija), dok su sile kopanja zadržane kao kod prvobitnog bagera.

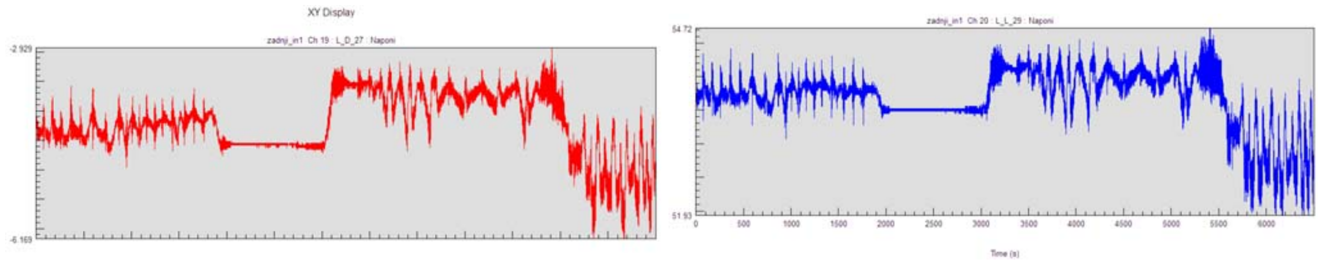
Na sl. 4 prikazani su brzi zapisi merenja pod opterećenjem na karakterističnim mestima. Na sl. 5 prikazani su zapisi merenja za duži vremenski period. Na sl. 6 prikazani su *rain-flow* dijagrami za levu i desnu lamelu za podatke sa sl. 7.

Calculation of the supporting superstructure

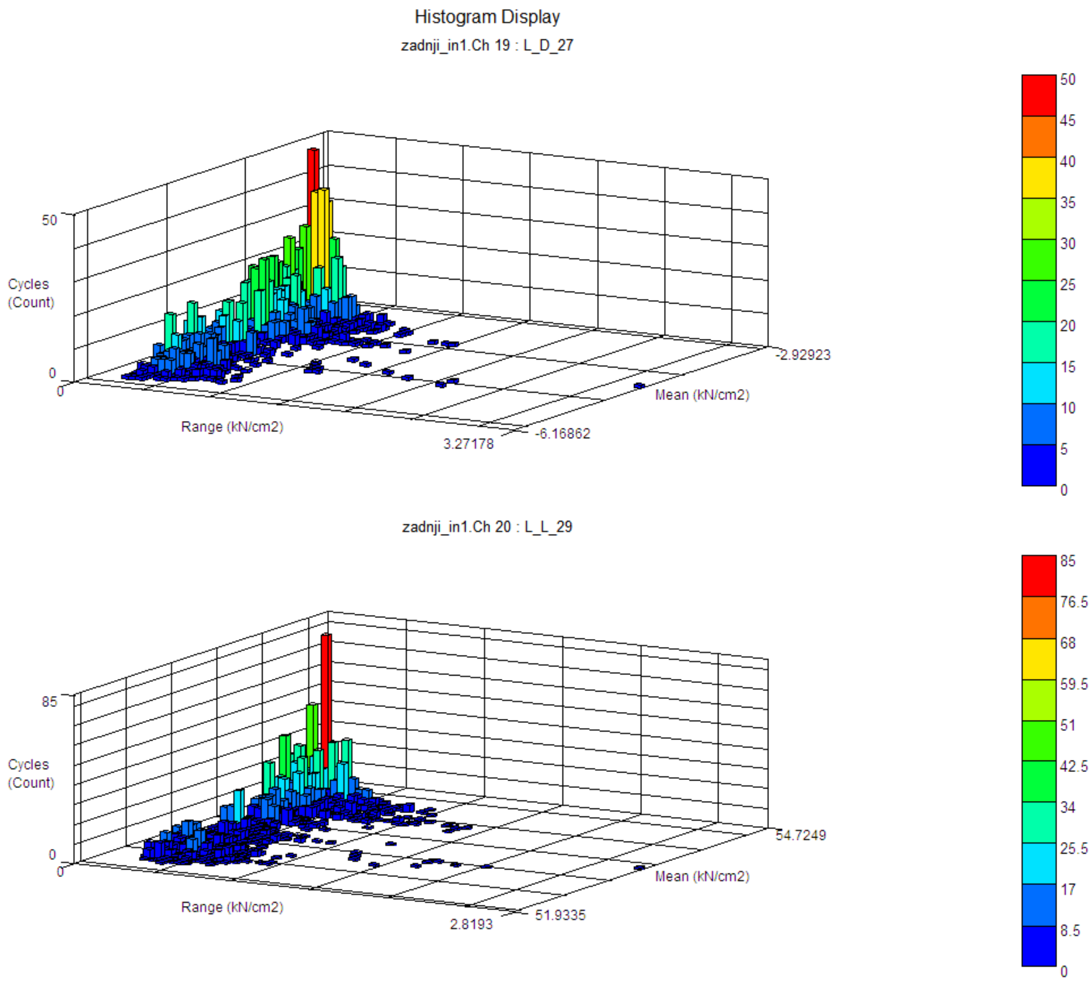
Calculation of supporting parts of the structure for both, the original, and the retrofitted machine (labelled SRs 1301) is performed by TAKRAF, Lauhammer according to East German standard TGL. The calculation for the superstructure is made only for retrofitted machine.

The highest difference between the old and retrofitted structure is caused by increase in mass of electrical equipment on the counterweight (frequency regulation), while the digging force was retained as originally applied.

Figure 4 shows fast records measurements at specific places. Figure 5 show longer time measurements. In Fig. 6, the rain-flow diagrams for left and right lamellae are shown according to data in Fig. 7.



Slika 5. Zapis sa merenja na lamelama u trajanju od 6000 sekundi
Figure 5. Records from gauges on lamellas, duration 6000 s.



Slika 6. *Rain flow* dijagram, leve i desne lamele (L-L, L-D)
Figure 6. Rain flow diagram, lamellae (L-L, L-D).

ZAKLJUČAK

Pristup u ovom radu zasnovan je na sveobuhvatnom prilazu dijagnostici koja se sastoji iz niza tehnika za dobijanje kvalitetnih rezultata o stanju i ponašanju konstrukcije, preko izrade računskih modela, obrade metodom konačnih elemenata, iterativnog usaglašavanja sa eksperimentalnim rezultatima. Ovo prolazi kroz primenu propisa i standarda, kroz višedecenijsko iskustvo u radu i održavanju mašina i uređaja.

Ova metodologija je „učenje" kako treba neku konstrukciju dijagnostički obraditi, iterativno usaglasiti izmerene veličine sa računskim veličinama u potrebnom broju koraka, a zatim to primeniti i na druge konstrukcije, pa i relativno nove, u cilju provere očekivanog ponašanja.

Prikazani rezultati u primeru rotornog bagera SRs 1301 opravdavaju ovaj dijagnostički pristup. U ovom slučaju je bila nedostupna dokumentaciju, uključujući podatke o materijalu, uslove i statističke pokazatelje eksploatacije od kada je montiran, 1982. godine, a prethodni proračun nije bio saglasan sa merenim podacima. Za primenu ovog pristupa bitno je usaglašavanje proračuna i izmerenih rezultata tako da se prvo razmatra slučaj opterećenja „bager spreman za rad" (samo sopstvena težina). Zatim se iterativnim postupkom za bagere slične konstrukcije može redukovati broj mernih mesta i koristiti već provereni proračun, što sa sigurnošću pokazuje ponašanje konstrukcije u radu i omogućava efikasan i siguran pristup i drugim mašinama.

CONCLUSION

The approach in this paper is based on the comprehensive approach to diagnostics that consists of a variety of techniques for obtaining high quality results on the state and behaviour of structures, as going through mathematical models, processing finite element method, iterative convergence with experimental results, that are verified by regulations and standards, through decades of experience in the operation and maintenance of machines and devices.

This methodology is "learning" on how some structure should be diagnostically treated, with iterative matching up measured values with calculated ones within the necessary number of steps, and then applying this to other structures, even relatively new, in order to check the expected behaviour.

Presented results in the case of the bucket wheel excavator SRs 1301 confirmed this diagnostics approach. In this case the documentation was not available, including material data, conditions and statistics of service from assembly in 1982, and preliminary calculation did not agree with measured data. To implement this approach it is important to conform the calculation and measured data, considering first the case load "bucket wheel excavator ready to work" (dead load only). Afterwards, the iterative procedure for excavators of similar design makes it is possible to reduce the number of measuring points and use confirmed calculation, giving a certainty of structural behaviour in service and enabling efficient and safe use of other machines.

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