Przemysław Moczko
Associate Professor
Wroclaw University of
Science and Technology
Faculty of Mechanical Engineering
Poland

Damian Pietrusiak
Assistant Professor
Wroclaw University of
Science and Technology
Faculty of Mechanical Engineering
Poland

Eugeniusz Rusiński
Professor
Wroclaw University of
Science and Technology
Faculty of Mechanical Engineering
Poland

Material Handling and Mining Equipment - International Standards Recommendations for Design and Testing

Bucket wheel excavators, spreaders, reclaimers etc. are a group of heavy machines commonly used in the mining, power and bulk-handling industry. As machines of this type are used worldwide in various operational conditions, different design and testing approaches were developed. The paper presents and compares the theoretical assumptions stated in most common standards (DIN, AS, ISO, BG...) as well in the technical and scientific literature. Moreover, the paper presents real life application giving this way the opportunity for reliable assessment of the obtained results over the normative theoretical assumptions.

Keywords: *design standards, mining equipment, material handling, simulations, testing*

1. INTRODUCTION

There is a big group of heavy and complex opencast mining and material handling machines that have a great importance for many industries that rely on them. Open pits of different geological supplies, transshipment harbors, storage facilities of organic and non-organic bulk materials and many other locations require such machines, which are usually core equipment, designed for many years of operation [1]. Exemplary structures are presented in figures 1 and 2 below.

Figure 1. Stacker-Reclaimer at the coal yard

Therefore there is common expectation of industry users to get machines that offer low cost of operation through the entire operational life. This is a big challenge for suppliers and designers of such equipment.

Design and testing of specialized mining and material handling equipment [2] is described in many standards that refer to different groups of machines, countries or regions of applications or sometimes national regulations for applications. Such a situation imposes on designers the use of different standards in order to run properly and quickly at both the preliminary and detailed design stages. The similar situation refers to tests and operation of this type of machines.

Figure 2. Bucket Wheel Excavator in the open pit

Considering above, a good knowledge of applicable standards in the designing and testing of specialized mining and material handling equipment, is the key for successful design and operation. There are many requirements, proofs and calculations approaches presented in different, applicable standards. The most important are discussed in the following chapters.

2. MAIN ASSUMPTIONS

Designing of specialized mining and material handling equipment refers to few standards, which were developed through many years of experience gathered by scientists and designers. The most common and historically important standards are listed below.

BG 1986 – Calculations and dimensioning of large machines in open cuts. German regulations applicable for opencast mining machines. This document is discontinued but mentioned in the paper as a background for other standards.

DIN 22261- Excavators, Spreaders and Auxiliary equipment in opencast lignite mines. The DIN 22261 standard has come into force in June 1997 and replaced

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Correspondence to: Przemyslaw Moczko, Assistnat Professor, Faculty of the Mechanical Engineering, Wroclaw University of Science and Technology, Poland
E-mail: przemyslaw.mozcko@pwr.edu.pl
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the BG 1986 regulations. The standard is applicable for specialised opencast mining equipment. It consists of six sections. However for design and testing of load carrying structures the most applicable sections are as follows:

- Part 1 : Erection, Opening and Tests.
- Part 2 : Principle of Calculation.
- Part 3 : Welding connections – Type of seam, groups of estimation, test instructions.

FEM 2.131/2.132 Rules for the design of mobile equipment for continuous handling of bulk materials. This standard was published in 1978. This document was revised in 1992 and forms a background for ISO 5049 standard.

ISO 5049 - Mobile equipment for continuous handling of bulk materials. This standard was published in 1994 and it is applicable for all stacking and reclaiming of bulk material handling equipment. This is the most commonly used standard for material handling equipment but not applicable for opencast mining machines where DIN 22261 is adopted.

AS 4324.1 Mobile equipment for continuous handling of bulk materials - General requirements for the design of steel structures. This standard was published in 1995 but the first works on this standard were commenced in 1978 [1]. This standard is based on BG 1986 and ISO 5049 standards. Therefore is covers bulk material handling equipment but is also applicable for specialised opencast mining equipment.

There are a few more standards which are more comprehensive (EUROCODE) or less popular (AA standards) or discontinued (TGL) but they are not discussed in this paper.

Among all standards mentioned above the most internationally recognised and commonly used in the industry are DIN 22261, ISO 5049 and AS 4324.1.The design rules and guidelines presented in the above standards will be discussed in the next chapters. They are focused on design approaches with respect to the static and dynamic loads which lead to strength and fatigue resistance. Stability calculations methods are discussed as well as they influence safety of machines significantly.

2.1 DESIGN WITH RESPECT TO STATIC LOADS

Design with respect to static loads refers to safety of opencast mining and material handling equipment from the strength and buckling point of view at the most. Therefore the most significant impact on the design quality has identification of loads, which must represent real operation condition of designed machine.

In the mentioned standards the permissible stress approach is commonly used in the designing process. However, it is possible to use limit state approach as well (AS 4324). In the permissible stress approach certain safety coefficients are used for certain load combinations. It is common practice in designing standards to group loads based on their frequency or probability of occurrence. In the DIN22261 standard there are four loads groups:

H (haupt from German)-main loads (including fatigue load combinations), HZ (haupt zusätzlich) - main and additional loads, HZS (haupt zusätzlich speziell) main, additional and special loads, HZG (haupt zusätzlich grenz)-main additional and extraordinary loads.

In the ISO5049 there are three load groups: Group I-main loads, Group II-additional loads, Group III-special loads.

The AS 4324 uses similar approach to ISO 5049 but there is additional fatigue load combination F/I taken from DIN 22261 standard (H1b).

Each load combination group refers to safety coefficient, which is considered in the permissible stress approach. The summary of safety coefficients listed in each standard is presented in table 1.

Table 1. Safety coefficients and load combinations

Standard	Load combinations			
	H1a/I	HZ/II	HZS/III	HZG/III
DIN 22261	1.5	1.33	1.2	1.1
ISO 5049	1.5	1.33	1.2	
AS 4324	1.5	1.33	1.2/1.1/1.0	

The less complex standard from the safety coefficients point of view is ISO 5049. In this standard only three values are used for permissible stress calculations, while DIN uses four and AS five numbers. More significant differences are present in the decisive loads considerations in each load combination group. For the main loads all standards consider the same type of loads. However, the second group of loads – main and additional is different. In the DIN standard there are two load combinations in this group:

- HZ2 - in operation, normal operation loads and operational wind are considered,
- HZ3 – out of operation, where storm wind is decisive load.

In the ISO standard there is one load combination:

- II – in operation, normal operation including operational wind, permanent and non-permanent dynamic loads are considered and decisive load is extraordinary digging and side force.

In the AS standard there are four load combinations:

- II/1 – in operation, similar combination as in ISO but abnormal inclination is included instead of operational inclination,
- II/2 - in operation, similar combination as in DIN HZ2
- II/3, II/4 – out of operation, similar combination as in DIN HZ3 with and without material and inclination considered.

The third group of loads consists of 13 load combinations in DIN, 9 in ISO and 16 in AS standard. In general, load combinations in this group are interchangeable. However in the AS standard there is III/6 load combination where both excessive material on conveyors and blocked chutes are to be considered. In the DIN and ISO these two special loads are considered in two separated load combinations. In machines with long booms and chutes located at the boom's tip, this load combination is a usually decisive one from the strength and stability point of view. Another special load combination of AS standard, which is not present in DIN or ISO, is III/14 where loss of bucket wheel and drive is to be considered. This combination together with catching hooks requirement for open ball races (main slew bearing of slewing superstructure) makes design of machines with the use of AS standard more challenging.

The above information refers to different ways of loads consideration in the load combinations groups.

Other differences between mentioned design standards can be found in the way of elementary loads calculations. Few of the most significant examples are listed below.

The AS standard requires application of additional safety factor of 1.1 in digging and side force calculations (for inaccuracies settings of protection devices against overloads). Another significant difference is found in relation to grounding loads (A, AA, A1, A2) calculations and considerations. AS standard requires considering two partial grounding levels or one partial grounding level and full grounding instead. This requirement is applicable for bucket wheel booms and other booms (discharge, stacking booms) as well. While DIN standard does not require considering grounding loads for spreaders stacking booms. Discharge and receiving booms are excluded. Abnormal inclination in transit for crawler mounted machines in AS and ISO standard must be increased for 20% as additional safety against this special load. However, in DIN standard this requirement does not exist.

As a general conclusion from the comparison of DIN 22261, ISO 5049 and AS 4324 standard, it can be found that:

- The most comprehensive standard for material handling and also opencast mining machines is AS 4324 standard.
- DIN 22261 is considered as well detailed and safe standard for opencast mining machines.
- ISO 5049 standard provides enough guidelines for experienced designers only.

The highest requirements in regards of load combinations and elementary loads calculations are listed in the AS standard as a result of many failures that occurred in Australian industry before introduction of this standard. These requirements have improved safety and reliability of material handling machines. However they have also significant impact on the dead weights of them, which are approximately up to 20% heavier than machines designed with the use of ISO or DIN standards.

What is worth mentioning is the AS 4324 standard recommends purchaser of the equipment to hire audit engineer (Independent Expert) for check and approval of the design. Authors of this paper have a status of Independent Expert for specialised mining and material handling equipment. During the last 20 years approximately 50 of different type of such machines have been covered by such consultancy services and many design and manufacturing faults have been found or prevent.

2.2 DESIGN WITH RESPECT TO DYNAMIC LOADS

One of the main determinants of the structure design, in terms of vibrations, are the dynamic factors which are taken under consideration in calculation as a substitution of dynamic loads. However, its definition differs with respect to the standard which is used. As already mentioned the three standards can be distinguished when talking about the design of load carrying structures of heavy bulk material handling machines: DIN 22261-2, AS 4324.1, ISO 5049.1.

Australian Standard, in case of fatigue and dynamics, defines dynamic factors as the German standard. However, the values of those factors are much higher than the German ones. Big disadvantage of both standards is the fact that the procedure of experimental determination of those factors is not described. Reader experienced in Digital Signal Processing (DSP) is aware that the signal post processing is crucial in case of evaluation of such parameters. Lack of the clear definition leads to the situation where it might be difficult to compare results if the procedures differ. The last standard (ISO) gives least of all information about dealing with dynamics, while it does not define dynamic factors and its level at all.

The dynamic effects factor ψ for the design of large-scale machines [4][5][6], is originally defined in German standard. Measured peak-to-peak acceleration value is compared with the constant value of gravitational acceleration (1). The ratio obtained in this way becomes the main indicator and tool for dynamic (in fact quasi-static) and fatigue calculations:

$$\psi = \frac{\Delta a}{g} \tag{1}$$

$$\Delta a = \max a - \min a$$

Operational processes in surface mining very often characterizes non-stationary nature. Relating the factor directly with the minimum and maximum observed acceleration value, makes it highly susceptible for any incidental event. The quasi-static approach which introduced the ψ factor, neglects the essence of dynamics phenomena in the investigated objects. A general accepted approach does not require to analyse of structure dynamic response, resonant excitation presence e.g. by the overlapping of excitation derived from excavation frequency with mode shapes. The only recommendation for such examination can be found in Australian standard. The authors of the paper carried out modernizations, [7] and [8], covering all presented recommendations. They developed many of the procedures and methods for experimental validation, including the dynamic loads. Referring to DIN standard appendix, example measurement can be found, however without any detailed instruction how to perform such tests. Lack of those information makes difficult to reproduce similar measurements and compare the results. Figure 3 presents the measurement points grid (presented in DIN). Experienced investigator notices that location of those points will not give comprehensive information about machine dynamics.

No explanation is given how the points location was determined. Especially interesting are points located at the undercarriage. Considering the nature of vibrations of presented structures, no significant signal at those points should be expected. This could give the answer why no values for undercarriage are given in the table with dynamic loads factor. Nevertheless, assumption that the superstructure dynamics do not affect the undercarriage is not correct.

Similar approach to objects dynamics assessment, with use of the factor for static calculations, is presented in cranes design, however the dynamic load factor is determined upon the dynamic forces generated by lifted mass. Characteristics of drives must be considered to derive mass forced related to the cargo load. That approach is present in the ISO standards.

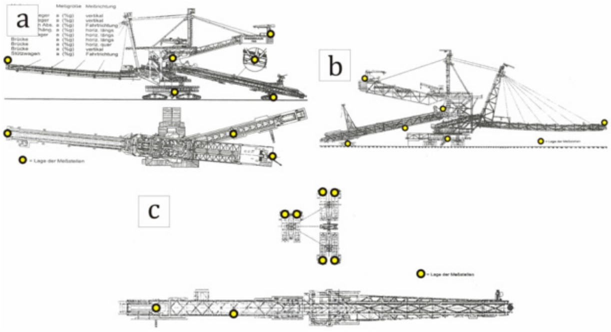

Figure 3. Distribution of measurement points [10]

In general, commonly accepted method of designing large-scale machines is based on the dynamic effects factor. As a consequence, the essential phenomena related to dynamic characteristics of the structures are neglected. Moreover, the actual definition of dynamic effects factor do not includes influence which superstructure dynamics can have for the undercarriage elements. There is lack of well-defined method for experimental testing of dynamics and validation of the design factors what leads to the situation where machines operate under unspecified dynamic loads, which often do not reflect the assumptions made at the design stage [9].

2.3 DESIGN WITH RESPECT TO FATIGUE STRENGTH

In this subchapter the issues related to the durability assessment will be described. First, the load definition will be described. Next, the short comparison of the fatigue calculations methods itself will be given.

According to the standard [10], which is the leading reference for surface mining equipment design, fatigue load case (H1b) consists of particular alternating loads: live loads - excavated material(F), inclination(N), digging force(U), lateral digging force(S), dynamic effects(D). The loads which change the direction of action in operation, must be multiplied while its alternation cause the stresses of amplitude twice that much. These loads are: lateral digging forces, inclination and dynamic effects. As a consequence the fatigue load case is defined by following loads

H1b: F, 2NQ, 2NL, U, 2S, 2DQ, 2DV, 2DL,

where inclination and dynamic loads consist of the directional components of the load. From the above definition of the H1b load case, it is clear that 3 of 8 components are related to the factor of dynamic effects. That fact emphasises the need of proper definition of dynamic loads due to its big influence on durability assessment.

In the latest release of DIN (2016) [11], the name of the fatigue load case was change for HD. The combination of the loads reminds unchanged, however a reader should be aware of the H1b and HD name change while for years the H1b became representative as durability/fatigue assessment case.

The Australian standard [12], as in many issues is similar to the DIN standard and defines the fatigue load case in the same way.

Standard which can also be taken under consideration while defining load for fatigue assessment is the ISO standard [13]. The separate fatigue load combination is not defined in this case. Recommendation is to use the loads defined in the Main Loads load case which can occur in more than 2x10^4 cycles. That identified loads should be implemented in calculations in the way that generates maximum tensile stresses. The ISO standard seems to give more independency in the fatigue load combination, but if that is to be done properly, should give combination similar to the combination defined in the DIN standard. In practice, many designers apply the DIN combination directly instead of developing it on the ISO recommendations.

The second issue is to assess the structure durability while the loads are already identified. Referring to the most used standard.- DIN. The infinite fatigue criterion is fulfilled when the resulting stress range remains below the fatigue limit specified for the specific type of structural node (connection type). In this approach influence of the cycles number related to particular load is neglected.

Quite similar method is used in the ISO standard. For specific connection charts with permissible stress for fatigue assessment are given However, the investigation is more detailed while proper durability curve selection requires information about the cycle character.

In the latest release of DIN standard (2016) the method for fatigue calculations was changed and unified with the recommendations for fatigue design according to the Eurocode 3, which base the durability assessment on the Palmgren-Miner damage cumulative approach. Damage cumulative method is already implemented in the AS standard. It is commonly used for the large scale structures in different industries, i.e. oil industry [14] and [15].

As the finite element method became the main engineering tool in last decades, it is also used for the fatigue assessment. However, big disadvantage of its application is its high sensitivity for the model parameters, which can highly influence the obtained model stresses. The geometric (hot spot) method is recommended while using FE analysis in fatigue calculations [16]. This requires the model to be prepared and the stresses readout with specified way [16,17].

2.4 STABILITY

In all mentioned standards (DIN 22262, ISO 5049, AS 4324 there is similar approach to stability calculations, which is based on the stability ratio ν_o calculated with the following equation (2):

$$\nu_o = \frac{M_S}{M_o} \tag{2}$$

where

M_s – the minimum stabilising moment calculated with respect of tipping axis

M_o – the maximum overturning moment calculated with respect of the same tipping axis

The above ratio shall be calculated for the most unfavourable load combinations and shall not be less than safety factors assigned to load combinations groups. However, there are certain differences in the results of stability calculations obtained from the mentioned standards. In the DIN 22261 standard there is additional requirement to multiply by 1.05 factor all permanent loads reducing the same stability of the machine. This is due to the fact that dead weights cannot be fully confirmed at the designing stage. Another difference, which is related to machines with slew bearings (with or without catching hooks), is the way of tipping axis diameter consideration, which should be calculated as 95% of the bearing radius. As per AS standard, there is requirement to install catching hooks in slew bearings always, so the proof of their strength assure safety of machine from the stability point of view.

As mentioned in the chapter 2.1 of this paper, there are also significant differences in load combinations and elementary loads calculations in the DIN, ISO and AS standards. The most restrictive AS standard imposes on designers many limitations regarding stability requirements. For example load combination III/6 (blocked chute and excessive material on conveyor) is usually decisive one in machines with long conveying booms equipped with chutes located at boom's tips. Similarly, requirement of boom grounding consideration for reclaiming or transfer machines (DIN does not requires this load for spreaders stacking booms) also makes stability requirements more difficult to fulfil.

Since stability of opencast mining and material handling machines has a great importance for safety of their operation it is not allowed to accept stability calculations with safety factors not fulfilling require–ments unlike to strength calculations where 5% over–stress can be accepted. This imposes demands on the designer to pay attention at the preliminary design stage of machines, where supporting systems, tipping axes dimensions and locations are set.

3. A STEP AHEAD of THE STANDARDS

As all the mentioned standards deal with the design of new machines, a big and common issue which is left unstandardized is technical condition assessment and residual life of the large structures after decades of operation. The service life of the new opencast or material handling machine is commonly specified for about 30 years of operation. However, there are more and more machines, which have already exceeded this age. The situation has a great importance due to the huge cost of a single machine and long delivery time of the new one. Therefore users face difficult decisions about the moment when machines worth millions should be scrapped and there is always a questions rising if the assumed durability has been already spent. Many years of operation in various conditions make this decision very difficult to be made. On the other hand, old machines must ensure proper safety of operation to prevent accidents causing human and money loss. The main problem in this case is the superstructure of the machine, which is in principle not subject to refurbishment, on the contrary to mechanical components of the machine.

Recent years brought many research works in this area [1], [20] and [21]. Authors of this paper have developed a comprehensive guide and recommendations for technical condition assessment, condition monitoring methods development and methods for operational live extension of such specialised mining and material handling equipment [8]. The main focus in the proposed solutions lies in the following activities:

- numerical identification of the stress effort by using three-dimensional computational models based on FEM, which then are used in the calculation of fatigue,
- identification of operational loads, which is carried out primarily with the use of experimental tests on investigated machines,
- residual life prediction based on the identified stress effort and the load acting on the analysed objects,
- implementation of proper condition monitoring approach to identify or predict failures of the structure at the earliest possible stage that enables corrective actions implementations,
- design and implementation of local or global modernisations of equipment with consideration of the above information on the technical condition of tested machine.

These studies complement the knowledge of the extent of degradation of the structure, assess its residual life and in most cases enables operational life extension with reasonable costs and expected safety level.

The second issue is that the standards and literature, when compared to the operational experience, points out a big discrepancy in the dynamic effects factors. Observations proved that the real values of dynamic factors do not cover the values assumed at the design stage [20]. This problem was marked and "solved" (increased values of dynamic effects factors, what leads to the the structure weight increase) in AS standard. Moreover, there is no recommendation for the validation of the assumed, on the design stage, values of the factor.

Recently conducted research [22] and [23] and developed method (Fig. 4) [9] fills the gap between the scientific calculation methods that are currently being developed in relation to dynamics of large-scale machines and the commonly known and used methods.

Because it is based on the dynamic effects factor for dynamic calculations, which, in accordance with standard recommendations is the basis for these calculations. The proposed method is compatible with all current requirements for designers of large-scale machines. It covers calculations, experimental validation and assessment. As a consequence the detailed control over dynamic behaviour is taken. The method was already validated and proved its effectiveness [20]. Additionally, the method, covers influences of the superstructure dynamics to the undercarriage structure [24]. Up to now, that correlation was neglected in most of the recommendations.

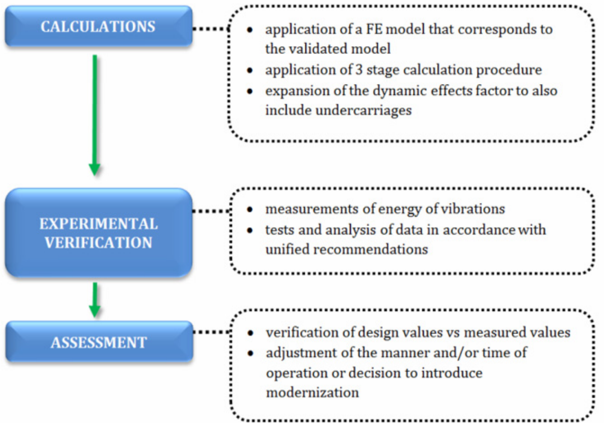

Figure 4. Method of evaluating large-scale load-carrying structures with the application of the dynamic effects factor [9]

4. CONCLUSION

Design and testing of specialized mining and material handling equipment requires a lot of knowledge and experience due to many applicable standards available. In the paper the three of them DIN 22261, ISO 5049 and AS 4324 are discussed. The main differences regarding loads assumptions, load combinations and calculations methods are presented. The highest requirements are listed in the AS 4324 standard as a results of many failures that occurred in Australian industry before introduction of this standard. However these requirements improve safety and reliability of the equipment, they have also significant impact on the dead weights of machines, which are approximately up to 20% heavier than machines designed with the use of ISO or DIN standards. It is worth noting that there is change in the fatigue calculations approach, which was recommended since longer time by scientists [25] and [26]. The cumulative damage approach (Palmgren-Miner) is more and more present in the standardised calculations.

However there are still gaps in the standards that need to be filled, to improve quality and safety of design tasks. The commonly accepted method of designing large-scale machines essentially neglects or underestimates the dynamics of the structures that are being designed. There is no standard that includes validated method of experimental tests which could be used to verify the actual values of the assumed dynamic factors. The DIN standard surprisingly neglects any of the dynamic or live loads by excluding undercarriage structures from fatigue calculations requirement.

Furthermore, existing opencast mining and material handling equipment needs to be properly assessed to obtain information on the technical condition and remainning time of safe operation. There are no standards that may help operators of such equipment to make decision about the moment when machines worth millions should be scrapped, or when, how and what to do to extend their operational life with an acceptable safety [27]. As a result of such situation there are many failures of opencast mining and material handling equipment occurring in the operation that sometimes create fatal consequences in human resources (injures, death cases) and quite often generate huge costs as well. Examples of such failures are presented in figures 5 and 6.

Figure 5. Catastrophic failure of the Bucket Wheel Excavator

Figure 6. Failure of the bucket wheel structure

Authors of this paper propose a comprehensive guide and recommendations for technical condition assessment, condition monitoring methods development and methods for operational live extension of such specialised mining and material handling equipment [8]. The proposed activities enable operators to maintain safe and economically justified operation.

REFERENCES

[1] Kasztelewicz Z. (2012) Koparki wielonaczyniowe i zwałowarki taśmowe. Technologia pracy.ART-TEKST Publishing House

[2] Zamiralowa E., Lodewijks G. Shape Stability of Pipe Belt Conveyors: From Throughability to Pipe -Ability, FME Transactions (2016) 44, 263-271

[3] Morgan, R. C. (2011) Design of Materials Handling Machines to AS4324.1-1995, Australasian Structural Engineering Conference, Perth 2012

[4] Bosnjak S. M, Oguamanam D C D, Zrnic N D. The influence of constructive parameterson response of bucket wheel excavator superstructure. Archives of Civil and Mechanical Engineering 2015; 15: 977-985

[5] Bosnjak S. M, Gnjatović N, The Influence of Geometric Configuration on Response of the Bucket Wheel Excavator Superstructure, FME Transactions (2016) 44, 313-323

[6] Brkić A Đ, Maneski T, Ignjatović D, Jovančić P, Spasojević Brkić V K. Diagnostics of bucket wheel excavator discharge boom dynamic perfor–mance and its reconstruction. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (2): 188–197

[7] Rusinski E, Dragan S, Moczko P, Pietrusiak, D. Implementation of experimental method of determining modal characteristics of surface mining machinery in the modernization of the excavating unit. Archives of Civil and Mechanical Engineering, 2012; 12(4):, 471–476, ttps://doi.org/10.1016/j.acme.2012.07.002

[8] Rusinski E., et al.: Surface mining machines : problems of maintenance and modernization. Cham : Springer, cop. 2017

[9] Pietrusiak D., Evaluation of large-scale load-carrying structures of machines with the application of the dynamic effects factor, Maintenance and reliability 2017; 19 (4): 542–551

[10] DIN 22261-2 Excavators, Stackers and Auxillary Equipment in Brown Coal Open Cut Mines Part 2 Calculation Principals, German Institute for Standardization, 2015

[11] DIN 22261-2 Excavators, Stackers and Auxillary Equipment in Brown Coal Open Cut Mines Part 2 Calculation Principals, German Institute for Standardization, 2016

[12] AS4324.1: Mobile equipment for continuous handling of bulk materials Part 1 - General requirements for the design of steel structures, Standards Australia, 1995

[13] International Organization for Standardization, ISO5049.1: Mobile Equipment for the Continuous Handling of Bulk Materials Part 1 Rules for the Design of Steel Structures, 1994

[14] DNV GL, RP-203: Fatigue design of offshore steel structures, 2014

[15] Norsork Standard 004, Design of streel structures, 2004

[16] EN 1993-1-9 (2005) (English): Eurocode 3: Design of steel structures - Part 1-9: Fatigue

[17] Hobbacher A.F., Recommendations for Fatigue Design of Welded Joints and Components, Sprin–ger International Publishing Switzerland 2016

[18] Niemi E; Fricke W, Maddox SJ, (2006). Fatigue Analysis of Welded Components - Designer's Guide to the Structural Hot-Spot Stress Approach, Woodhead Publ., Cambridge

[19] Arsić, M., Bošnjak, S., Zrnić, N., Sedmak, A., Gnjatović, N.: Bucket wheel failure caused by residual stresses in welded joints, Engineering Failure Analysis, Volume 18, Issue 2, March 2011, Pages 700–712

[20] Rusiński E., Moczko P., Pietrusiak D., Low frequency vibrations of the surface mining machines caused by operational loads and its impact on durability, Proceedings of ISMA2014 International Conference on Noise and Vibration Engineering : USD2014 International Conference on Uncertainty in Structural Dynamics, Leuven, 15 to 17 September, 2014 / eds. P. Sas, D. Moens, H. Denayer. Haverlee : Katholieke Universitet Leuven. Department Werktuigkunde, [2014]. s. 683-694

[21] Stamboliska Z., Rusiński E., Moczko P.: Proactive Condition Monitoring of Low-Speed Machines, Springer International Publishing Switzerland 2015. ISBN 978-3-319-10493-5, 2015

[22] Pietrusiak D., Moczko P., Rusiński E., Recent achievements in investigations of dynamics of surface mining heavy machines, 24th World Mining Congress Proceedings , October 18-21, 2016, Rio de Janeiro, Brazil. Rio de Janeiro : IBRAM,. s. 295-308, 2016

[23] Pietrusiak D., Moczko P., Rusiński E., World's largest movable mining machine vibration testing - numerical and experimental approach. Proceedings of ISMA2016 International Conference on Noise and Vibration Engineering, 19 to 21 September, 2016 / eds. P. Sas, D. Moens, A. van de Walle. Leuven : Katholieke Universitet Leuven, s. 2287-2299, 2016

[24] Pietrusiak D., Smolnicki T., Stańco M. The influence of superstructure vibrations on operational loads in the undercarriage of bulk material handling machine, Archives of Civil and Mechanical Engineering. 2017, vol. 17, nr 4, s. 855-862

[25] Rusiński E., Moczko P., Derlukiewicz D.: Use of finite element method in designing and operation of basic machines of open-cast mining, Zbornik na Trudovi - Masinski Fakultet Skopje. 2004, G. 23, br. 2, s. 49-57

[26] Rusiński E., Moczko P.: Evaluation of durability of elements of load-bearing structures, Design and selection of bulk material handling equipment and systems: mining, mineral processing, port, plant and excavation engineering. Vol. 2 / ed. by Jayanta Bhattacharya. Kolkata : Wide Publishing, 2012

[27] Bosnjak S, Petkovic Z, Simonovic A, Zrnic N, Gnjatovic N. Designing-in failures and redesign of bucket wheel excavator undercarriage. Engi–neering Failure Analysis 2013; 35: 95–103

ТРАНСПОРТНА И РУДАРСКА ОПРЕМА – ПРЕПОРУКЕ МЕЂУНАРОДНИХ СТАНДАРДА ЗА ПРОЈЕКТОВАЊЕ И ИСПИТИВАЊЕ

П. Моћко, Д. Пиетрусиак, Е. Русински

Роторни багери, растурачи, конвејери, итд. чине групу тешких машина које се најчешће користе у рударској, електро-енергетској и индустрији за пренос расутих материјала. Како се машине овог типа користе широм света у различитим радним условима, развијени су и различити приступи за њихово пројектовање и испитивање. Рад приказује и упоређује теоријске претпоставке наведене у најчешће примењиваним стандардима (DIN, AS, ISO, BG...) као и у техничкој и научној литератури. Рад такође приказује примену стандарда у реалном животу, при чему се стварају услови за поуздану процену добијених резултата у односу на нормативне теоријске претпоставке.