Wiesław TOMCZYK, Zbigniew KOWALCZYK
Uniwersytet Rolniczy w Krakowie, Wydział Inżynierii Produkcji i Informatyki, Instytut Inżynierii Rolniczej i Informatyki
ul. Balicka 116B, 30-149 Kraków, Poland
e-mail: Wieslaw.Tomczyk@ur.krakow.pl ; Zbigniew.Kowalczyk@ur.krakow.pl

THE WEAR PROCESSES IN THE ASPECT OF CONSTRUCTION QUALITY AND THE NEED TO APPLY AGRICULTURAL MACHINES SERVICING

Summary

In the Polish agriculture, farm vehicles, machines and devices with a varied complexity and modernity of structural solutions are used - from simple (harrow, plough) to very modern (combine harvester, beetroot harvester, tractor, sprayer). A considerable complexity of processes, mechanisms and phenomena, which take place during their operation and considerable wear and age in the light of stricter requirements concerning the scope of environmental protection, enforce the necessity to know them and to develop a new quality approach to the issues of rational use and operation of machines and devices in order to minimize effects and results of their operating wear. Operating wear is an inseparable phenomenon in the process of use of all machines and devices and in case of agricultural machines it is significant (no possibility to stop the agricultural production process and thus incurred irreparable losses). Intensity of this wear is influenced by various factors - originating in design, structure, technology and operating wear. "The operating quality" of machines in the aspect of their reliability to perform production tasks and the need to use adequate servicing in order to maintain them at a respectively high level are a significant issue within this scope. The basic aim of the author's research was to present the problem of shaping the structural quality of machines, carrying out the analysis of the observed types and processes of agricultural machines wear and tear and presentation of the obtained operation tests results in the aspect of operating wear of machines and devices with which investigated farms are equipped in the context of justification for servicing.
***Key words**: agricultural machine, operating wear, construction criteria, reliability, repair, restoration*

PROCESY ZUŻYCIA W ASPEKCIE JAKOŚCI KONSTRUKCJI ORAZ POTRZEBY STOSOWANIA OBSŁUGI TECHNICZNEJ MASZYN ROLNICZYCH

Streszczenie

W rolnictwie polskim użytkuje się pojazdy, maszyny i urządzenia rolnicze o skrajnie zróżnicowanej złożoności i nowoczesności rozwiązań konstrukcyjnych – od prostych (brony, pługi) do bardzo nowoczesnych (kombajny zbożowe, buraczane, ciągniki, opryskiwacze). Znaczna złożoność procesów, mechanizmów i zjawisk, jaka ma miejsce podczas ich eksploatacji oraz znaczne zużycie i wiek, w świetle zaostrzonych wymagań z zakresu ochrony środowiska przyrodniczego wymuszają konieczność ich poznania oraz opracowania jakościowo nowego podejścia do zagadnień racjonalnego użytkowania i obsługiwania eksploatowanych maszyn i urządzeń w celu zminimalizowania następstw i skutków ich zużycia eksploatacyjnego. Zużycie eksploatacyjne jest nieodłącznym zjawiskiem w procesie użytkowania wszystkich maszyn i urządzeń, a w przypadku maszyn rolniczych ma to szczególne znaczenie (brak możliwości zatrzymania procesu produkcji rolniczej i ponoszone stąd nieodwracalne straty). Na intensywność tego zużycia mają wpływ różne czynniki – pochodzenia projektowego, konstrukcyjnego, technologicznego oraz eksploatacyjnego. Istotnym pojęciem w tym zakresie jest „jakość eksploatacyjna" maszyn w aspekcie ich niezawodności w realizacji zadań produkcyjnych oraz potrzeba stosowania adekwatnej obsługi technicznej, by ją utrzymać na odpowiednio wysokim poziomie. Zasadniczym celem badań autorów było przedstawienie problemu kształtowania jakości konstrukcyjnej maszyn, przeprowadzenie analizy zaobserwowanych rodzajów i procesów zużycia maszyn rolniczych oraz prezentacja uzyskanych wyników badań eksploatacyjnych w aspekcie zużycia eksploatacyjnego maszyn i urządzeń będących na wyposażeniu gospodarstw objętych badaniami w kontekście zasadności prowadzenia obsługi technicznej.
***Słowa kluczowe**: maszyna rolnicza, zużycie eksploatacyjne, kryteria konstrukcyjne, niezawodność, naprawa, odnowa*

1. Introduction

The Polish agriculture despite constant restructuring in many cases is characterized with a low efficiency of production arising from improper agrarian structure of farms, underinvestment and high capital intensity. The Polish agriculture in many cases has machines with a prolonged period of exploitation (20-30 years) and a low level of technical preparation of users to operate modern structures of machines and devices. Profitability of agricultural production depends heavily on the level of costs related to the system of machines operation. In order to face the competition within this scope, one should aim to reduce the agricultural production costs, to reduce employment through a rational increase of the degree of works mechanization and automation of production processes and reduction of machines operation costs. Organizational issues and costs of use of agricultural machines in conditions of constant restructuring of the national agriculture, widely understood renovation of the machinery park (renovation of old structures, purchase of new machines), common competition on the market of agricultural production, requirements within the scope of the quality of the purchased food, obeying standards and rules concerning environmental protection pursuant to EU Directives etc. are a significant challenge for an operational and repair base of the Polish agriculture [5, 10, 20].

Modern agricultural technologies, which ensure high production performance depend mainly on constant implementation to the practice of the newest achievements of

scientific and technical progress within the scope of construction and highly efficient operational systems and at the same time very complex agricultural machines (farm tractors, combines, etc.). The operation systems of agricultural machines include presently all issues related to their use, restoration, endurance and reliability of machines, fuel and grease management, supplying with machines and their spare parts, preparation and education of staff for operational needs and creation and organization of service and repair base etc. A superior principle of correct functioning of such systems of agricultural machines operation is to ensure correct and reliable execution of all indispensable works, engaging minimum technical means and financial inputs [1, 6, 7, 11].

Agricultural production is characteristic since particular works are not regularly distributed during a year and dates of their performance depend on changing climatic and environmental factors and cannot be shifted randomly. Machines and devices used in agricultural production during their operation are subject to constant intensive and accelerated processes of tribological wear, in case of which friction phenomena are important. It is caused, inter alia, by abrasion of moving parts, surface corrosion, material fatigue and other similar physical phenomena. Irregularity of wear and tear of particular elements of machines and devices enforces the necessity to carry out servicing (e.g. repair). Degree of wear and tear of particular elements (units) of machines increases along with time proportionally to the intensity of their work [12, 13, 14, 15, 18, 25].

A need to develop and maintain the production in farms with various area structures at a high quality level is related to ensuring optimal efficiency and reliability and better use of the tractor and machinery park, and remaining devices. It mainly depends on security of supplies, relatively cheap with high operational quality of parts and spare units and the repair and service back, which is efficient and functions correctly.

Repair costs constitute a considerable element of operational costs of agricultural machines. The value of servicing for particular machines is 40-150% of the purchase price in the entire period of its use [19]. For deficiency and high prices of new parts and spare units a constant development of various organizational methods and forms of their restoration (including renovation of parts) is a favourable solution. A significant factor, which has a fundamental impact on reduction of agricultural production costs, consists in a reduction of exploitation costs of machines and devices by their widely understood renovation, i.e. repair with the use of brand new parts and recovered by repair, partially worn - regenerated (reduction of material costs of repair). This method is popular in developed countries (Germany, England, France, USA etc.) because thus the maintenance costs of machines may be reduced by even 60-70% limiting at the same time the environmental pollution (scrapping worn machines) and reducing energy and work inputs on production of new spare parts [2, 8, 18, 23, 27, 28].

Quality of machines and devices is a significant problem with regard to optimization of their operating costs. Structural quality is an individual property for each type of a machine and usually is directly proportional to their value (a purchase price). A user, when deciding to purchase a cheaper machine must be conscious of the risk and future consequences (low reliability, frequent faults and not planned stoppages of machines, disturbances in the production cycle, higher costs of exploitation etc. [7, 23].

The objective of the paper is to present the design and utility criteria of machines to carry out research and discussion on the results of operating wear of the selected types of machines and devices in the aspect of selection and justification for varied technical servicing.

2. The issue of quality of agricultural machines structure

A widely understood concept of the quality of used machines and devices is of significance in times of popular competition of producers on the market of goods and at a high market supply and stable demand. The need to carry out research in order to increase the quality and the belief in the profitability of investing is based on the international ISO standards series 9000, 2000, 2001 etc., which are more accepted by establishments which produce machines and devices and users of these machines (e.g. farmers). These standards explicitly indicate how a producer may design and make a particular machine, so it can perform its tasks, be a user and environmentally friendly. These machines both during operation as well as in the process of their scraping through a possibility of recycling (e.g. regeneration) of the selected parts and their reuse in the renovation processes (repair) and other similar types of machines, must be environmentally friendly. In order to meet the above assumptions, the possibility of operation in various stages of machines' life, must be considered to make them achieve a high quality during their long operation [9, 17, 20, 24].

A designer, when starting to solve a constructional problem, starts with the so-called design assumptions. Partially they are formulated by a commissioner of a design, partially they result from conditions and circumstances, in which machines and devices will be operated. A team of designers is obliged to take into consideration any demands and requirements of the future machine user and any reservations resulting from, inter alia, design errors similar with regard to the structure of the existing and utilised objects (by their removal). Project assumptions must also include utility criteria of the constructed machines and devices, which are fundamental at the final selection of a design. Properties, with which the conceptual and production design of new machines and devices should be endowed, should include complexity of operation problems. They may be brought to the so-called functional utility criteria.

Demands, requirements and wishes presented in the design assumptions are the basis for assuming those criteria.

If the demand is not met, a design solution cannot be accepted. Whereas, requirements, as the criteria are subject to optimization. Achieving maximum values e.g. at the reliability criterion or minimum criteria e.g. a criterion of costs is an objective. Wishes are non-obligatory proposals. They may be met, but do not have to. They constitute a system of significant criteria in sale of competitive solutions among producers (they are affected by the market rights and the so-called "fashion, taste and preferences" of future clients).

The above design and utility criteria may be of the quantity nature when their value may be defined with numbers (e.g. reliability, costs, etc.) or of the quality nature, when their value should be estimated acc. to the assumed scale of evaluation or objectivized (e.g. maintainability, threat to environment, etc.). Those criteria are set in a table 1 [2, 3, 9, 12, 25].

Constant variability of the technical condition during

their utilization is a specific property of the quality of exploitation of machines and devices. Changes of the device condition in time, which originate in the utility process affect the degree to which users' requirements are met by a given machine. The operating quality depends also on variability of users' requirements (which occur with a varied intensity as a result of e.g. seasonality and timeliness of some works in agrotechnical periods in agriculture; fashion and changing trends on the market of machines, e.g. modern, ergonomic, comfortable structures with aesthetic forms etc.). This problem is significant with reference to machines and devices used in agricultural production distributed in time on account of variability and complexity of parameters of agricultural environment (soil compaction and calcification, humidity, frequent changes of atmospheric conditions etc.). Generally, the exploitation quality of machines and devices at the moment of starting the exploitation is the highest and the lowest at the moment they achieve a border state (fault, damage). The quality of the machine is also a measure of their social utility value and one of the main factors of increasing the efficiency of operation and widely understood efficiency of management [10, 11, 16].

Conditions of utilization of machines and devices have a significant impact on their exploitation quality. It results from the fact, that the requirements of particular users towards the same type of machines are varied. With reference to the group of properties there is a distribution of requirements. A form of such distribution is an object of a detailed analysis carried out by designers, constructors and producers and should be the basis for optimization of parameters of newly designed machines.

The issue of shaping the quality of machines obtains presently even a higher rank and thus a complex operation within this scope should be carried out in various stages of the machine life. These undertakings must serve to obtain by these machines a high quality during their exploitation, the so-called "exploitation quality". This quality is shaped at all stages of the machine life, starting with demand or research of the market and marketing, through the stage of construction and production and ending with a user, where it is confirmed during realization of tasks in real conditions of operation in farms. The exploitation quality of machines is thus a function of operations at the stage of designing, production and conditions of their use (variable soil conditions in agriculture, varied professional skills of machines' operator etc.), which may be presented in the form of [25]:

$$J_E = f(J_p \times J_w \times J_u) \tag{1}$$

where:
J_E – the operating quality
J_p – the quality assumed at the stage of concept and design,
J_w – the utility quality achieved at the production stage,
J_u – the quality of the use

From the above it follows that the operating quality will be shaped by the group of real properties of a machine (J_w) in relation to the group of properties determined with formal requirements (standards: PN [Polish Standard], BHP [safety rules], environmental etc.) and design assumptions (J_p), which follow from the need on account of designation and utility functions which are met by a machine and conditions and manners of their use, which are specific for each farm (J_u), [12].

The issue of the quality with regard to restoration of damaged machines and devices used in agriculture is significant in the further process of their exploitation and use by farmers in their farms. In practice, users of machines and devices identify the quality of the goods through such properties as: functionality, reliability of operation, technical readiness, work safety, low exploitation costs, environmental friendliness, possibility of profitable recycling of scrapped machines, etc.

Table 1. Design and utility criteria of machines and devices
Tab. 1. Kryteria projektowo-użytkowe maszyn i urządzeń

Superior criteria	Utility criteria	Service criteria	Economic criteria
- threats for human life and health - threats for environment against destruction, damage or pollution	- reliability, - endurance, - ergonomic properties - susceptibility to operation - susceptibility to storing - susceptibility to control	- diagnostic susceptibility, - control susceptibility, - susceptibility to periodical servicing, - susceptibility to assembly and disassembly - replaceability of elements (unification, standardization), - technology of repairs, renovation and restoration, - susceptibility to organization of producer's services, - conditions for tests and running-in with users, - susceptibility to transport, - susceptibility to storage, - susceptibility to sitting in, - susceptibility to starting, - susceptibility to liquidation and recycling of an object	- proexport nature, - costs of use (labour, exploitation of materials), - costs of operation (staff, degree of speciality of a tool) - costs of transport, start-up, tests, - liquidation costs (utilization, recycling)

Source: Author's own research and based on literature [2, 3, 8, 12, 23] / Źródło: opracowanie własne oraz na podstawie [2, 3, 9, 12, 23]

3. Research on the process of wear and tear of agricultural machines - methodology of research, results and discussion

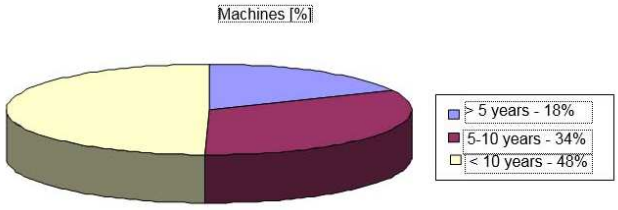
The longer the machines and devices are utilized, their operating quality is reduced. A change of the condition of the device in time, which has its source in the process of use, also affects the degree of meeting the users' requirements by a given machine. The problem is crucial in particular with regard to machines and devices used very intensively in relatively short agrotechnical periods of works in agriculture (when they have to be reliable) and frequently they are used by users (farmers) with a low skill level and low technical culture.

Agricultural machines used in agricultural production (plant, animal etc.) are exposed to frequent processes of operating wear (physical) of their particular parts. Those, which were caused due to this damage follow from tribologic wear, which takes place gradually along with a rising impact of destroying phenomena caused by friction of cooperating elements or contacts with foreign bodies (mineral bodies, sand, agricultural products such as hay, grain, manure, etc.). The main symptom of the wear processes are noticed while occurring surface loss of material (within 1-2 [mm]) and the loss of physical properties of these layers [14, 15, 18, 22, 27]. Tribologic wear is this type of wear, which may be only minimized, but it cannot be eliminated completely. Minimization will consist in the use of materials with a suitable quality (strength), precise treatment and adjustment of cooperating surfaces of elements and in the use of measures against friction (selection of an appropriate greasing system, high class of oils and greases) as well as precise and professional execution of indispensable servicing [26]. Knowledge of physical and chemical processes which threaten agricultural machines and thus the possibility of preventing them allows slowing down the ageing processes and reduction of the risk of faults (a random damage) and causes the reduction of their exploitation costs and indirectly also improves the economic condition of agricultural farms.

In 2011-2013, the author carried out a research in sixty farms in Małopolskie voivodeship. The investigated farms were not selected randomly but purposefully, i.e. there were the farms which met the EU criteria concerning commodity farms which operate based on the market economy criteria (full competition) and economical optimization. Farms covered by research were supposed to meet the following criteria:

- an agricultural production is the main source of income,
- they have farm tractors and the basic set of machines which cooperate with a tractor as well as other types of machines (e.g. combine harvesters, planters, seeders, collecting presses, transport trailers, manure and fertilizer spreader, cultivation units etc.),
- farmers are educated in agrotechnology principles with regard to agricultural production and the use of technical machines and devices (minimum at the level of a vocational school or a secondary school).

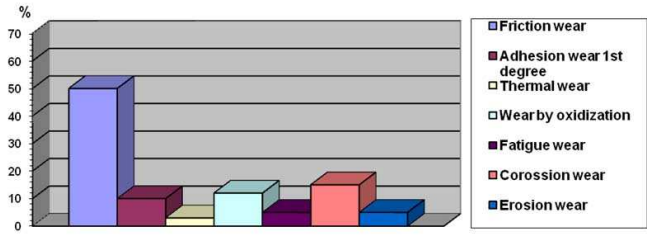
The research was carried out in the form of a guided survey based on the previously prepared questionnaire. The research covered in total 607 pieces of machines and agricultural devices with which the selected farms were equipped. Machines covered by the research were of a different age and with a different degree of exploitation (fig. 1).



Source: Author's own research / Źródło: opracowanie własne

Fig. 1. Age groups of machines
Rys. 1. Grupy wiekowe maszyn

The research which was carried out and the analysis of the types of operating wear of the investigated machines proved that the prevailing type of consumption includes friction and corrosion wear and the wear caused by oxidization (fig. 2). It is caused by a specificity of the machine use in agriculture (variable and varied soils and atmospheric conditions, seasonality of field works, long term stoppages of machines, low technical culture of machines' users (farmers), in many instances not professional (accidental) manner of servicing etc.).



Source: Author's own research / Źródło: opracowanie własne

Fig. 2. Percentage share of wear in damaged machines
Rys. 2. Procentowe udziały zużycia w uszkodzeniach maszyn

Machines utilized in farms were successively subjected to various treatments of servicing which were prophylactic and temporary in nature (periodical technical inspection, maintenance, current post -fault repairs and prophylactic etc.), which was presented in table 2.

All (100%) machines and devices in farms were regularly subjected to technical inspection, which is characteristic in this group of farms. Research carried out in the form of a guided survey among users of these machines proved that such a high percentage (100%) of the inspected machines resulted from care for their reliability during performance of urgent and timely farm works (spraying, haymaking, harvest, potato lifting, plant care works etc.).

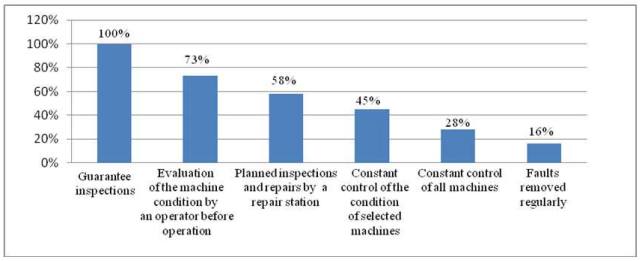
Technical inspections enabled finding the faults (malfunctions) and carrying out post-inspection repairs as well as prophylactic repairs. In case of technical services only farm tractors (100% of the quantity condition) were subjected to seasonal service on account of their use through the entire calendar year (the need to use suitable technological liquids in winter at negative temperatures, preparation of operator's cabin, etc.). Whereas, all the remaining machines and devices were in 100% subjected to the so-called campaign services (pre- and post - campaign) and tractors in approx. 58%. It was related to the necessity of maintaining them in full technical readiness before the following periods of use in the next agricultural production campaigns.

Table 2. The used technical services of machines and devices in the investigated farms
Tab. 2. Stosowane obsługi techniczne maszyn i urządzeń w gospodarstwach objętych badaniami

Machine type	type and number of used technical services / of the total number of machines [item / %]					
	Technical inspection	Repairs			Services	
		After inspection	After faults	Prophylactic	Seasonal	Campaign
Farm tractors	76 / 100	35 / 46	24 / 31.5	5 / 6.5	76 / 100	43 / 58
Ploughs	63 / 100	37 / 59	7 / 11	15 / 24	-	63 / 100
Cultivation units	30 / 100	14 / 47	5 / 17	-	-	30 / 100
Harrows	52 / 100	18 / 35	5 / 10	-	-	52 / 100
Soil millers	25 / 100	4 / 16	3 / 12	-	-	25 / 100
Slant wagons	11 / 100	3 / 27	4 / 36	-	-	11 / 100
Transport trailers	64 / 100	28 / 44	19 / 30	5 / 8	-	64 / 100
Fertilizer distributors	39 / 100	18 / 46	7 / 18	-	-	39 / 100
Sprayers	30 / 100	17 / 57	9 / 30	12 / 40	-	30 / 100
Manure spreaders	35 / 100	12 / 34	7 / 20	3 / 9	-	35 / 100
Potato diggers	20 / 100	7 / 35	5 / 25	1 / 5	-	20 / 100
Fodder mixers	13 / 100	4 / 31	2 / 15	-	-	13 / 100
Mowers	44 / 100	35 / 80	18 / 41	7 / 16	-	44 / 100
Haymakers-rakes	37 / 100	13 / 35	5 / 13.5	-	-	37 / 100
Combine harvesters	20 / 100	5 / 25	3 / 15	3 / 15	-	20 / 100
Potato harvesters	10 / 100	4 / 40	2 / 20	1 / 10	-	10 / 100
Cultivation and sowing unit	8 / 100	3 / 37.5	-	1 / 12.5	-	8 / 100
Dryers	2 / 100	1 / 50	-	-	-	2 / 100
Generators	17 / 100	-	-	3 / 18	-	17 / 100
Loading devices	11 / 100	3 / 27	-	1 / 9	-	11 / 100

Source: Author's own research / Źródło: opracowanie własne

Methods of supervision over machines (fig. 3) and the manner of realization of tasks related to their maintenance were analysed. A repair service was engaged in 100% for performance of the planned guarantee inspections. In 73% a machine operator assessed the technical condition preceding the operation. The additional data show that also treatments of cleaning and conservation of a machine were carried out after the campaign works (a harvest campaign, potato lifting campaign etc.) and qualifying tests which assessed the general technical condition of a machine. While, the manner of execution of technical services was varied since in 63% was carried out by owners of machines and only in 30% an external service was commissioned to repair stations and 7% of services were commissioned to the authorized repair stations (e.g. repair of injection pumps of feed systems with self ignition).



Source: Author's own research / Źródło: opracowanie własne

Fig. 3. Methods of supervision over machines
Rys. 3. Sposoby nadzoru nad maszynami

4. Conclusions

High exploitation quality of machines and devices should be the objective for all persons (designers, constructors, producers, users) engaged in developing new structures. Thorough recognition of needs concerning new construction solutions, clear and precise determination of requirements of future machines' and devices' users and taking them into consideration in a complex structure of a machine, at a possibly faultless duplication of a high quality in the production process through a very high creative quality - results in a proper structure of a device (machine) which has desired and expected exploitation properties.

One of the main elements of effective agricultural production includes maintaining farm tractors and machines in full technical readiness and maintaining high quality parameters in execution of their tasks. This purpose may be achieved by maintaining a machinery park of farms at a high quality of operation by recovering the worn exploitation potential of a machine, repairing damaged (worn) parts and units with the use in the recovery process of both new as well as regenerated parts (ecological aspect) and by carrying out technical services with a properly varied scope of operations corresponding to their actual technical condition (technical inspections, repairs, periodical services etc.).

The presented exploitation criteria of machines and devices are the basis for issues concerning optimization at the selection of proper designs of structures of specific types of devices on account of maintaining significant utility properties of machines from the point of view of a purchaser and a user. Optimization aims at the assessment of the design solutions concept and selection of the best variant. The presented exploitation criteria include demands, requirements and wishes. Demands have superior criteria and should be subject to the optimization procedure. Whereas, the remaining (requirements, wishes) are subject to such procedure. Only a sounding out and rational analysis of possibilities, needs and expectations (e.g. farmers) may consequently lead to construction and production of machines with high parameters of the operating quality, optimal wear and operation costs which are satisfying for a user.

The analysis of technical services of machines in the investigated farms indicates high consciousness of farmers

concerning the processes of operating wear of some machines and a proper selection and scope of their use in the aspect of maintaining optimal agrotechnical time limits of agricultural production (which in many cases may remain only a wish).

5. References

[1] Ahmad R., Kamaruddin S., Azid I., Almanar I.: Maintenance management decision model for preventive maintenance strategy on production equipment. J. Ind. Eng. Int., 2011, 7(13), 22-34.

[2] Alsyouf I.: Maintenance practices in Swedish industries: Survey results. International Journal of Production Economics, 2009, 121(1), 212-23.

[3] Al-Turki U.: A framework for strategic planning in maintenance. Journal of Quality in Maintenance Engineering, 2011, 17(2), 150-162.

[4] Arca J.C., Prado J.C.P.: Reflective practice; personnel participation as a factor for success in maintenance program implementation. International Journal of Productivity and Performance Management, 2008, 57(3), 247-258.

[5] Crespo Márquez A., Moreu de León P., Gómez Fernández J.F, Parra Márquez C., López Campos M.: Struktura zarządzania utrzymania: praktyczny widok do zarządzania utrzymania. Dziennik Jakości w Inżynierii Utrzymania, 2009, 4(8), 353-362.

[6] Downarowicz O.: Systemy eksploatacji. Zarządzanie zasobami techniki. Radom: ITE, 2000.

[7] Fatemeh H., Sha'ri M.Y.: Continuous improvement through an integrated maintenance model. Contemporary Engineering Sciences, 2011, 4(8), 353-362.

[8] Dreszczyk E., Malicki M.: Modele elastycznego inwestowania w maszyny rolnicze. Inżynieria Rolnicza, 1999, 5. ISSN 1429-7264.

[9] Hao Q., Xue Y., Shen W., Jones B., Zhu J.A.: Decision support system for integrating Corrective Maintenance, Preventive Maintenance, and Condition-Based Maintenance. Construction Research Congress, 2010, 470-479.

[10] Jurca V., Ales Z.: Maintenance management systems in agricultural companies in the Czech Republic. Eksploatacja i Niezawodność – Maintenance and Reliability, 2012, 14(3), 233-238.

[11] Kaźmierczak J.: Eksploatacja systemów technicznych. Gliwice: Wydawnictwo Politechniki Śląskiej, 2000.

[12] Kolman R.: Inżynieria jakości. Warszawa: PWE, 1992.

[13] Kowalczyk Z.: Zużycie wybranych typów ciągników rolniczych. Inżynieria Rolnicza, 2011, 4. ISSN 1429-7264.

[14] Królczyk G., Królczyk J.B., Legutko S., Hunjet A.: Effect of the disc processing technology on the vibration level of the chipper during operations process. Tehnićki Vjesnik – Technical Gazette, 2014, 21, 2, 447-450.

[15] Królczyk J.B., Legutko S., Królczyk G.M.: Dynamie balancing of the threshing drum in combine harvesters to reduce mechanical vibrations. Applied Mechanics and Materials, 2014, Vol. 693, 424-429.

[16] Legutko S.: Trendy rozwoju utrzymania ruchu urządzeń i maszyn. Eksploatacja i Niezawodność – Maintenance and Reliability, 2009, 42(2), 8-16.

[17] Maleszka A. Narzędzia sterowania jakością w polskiej gospodarce wolnorynkowej. Akademia Ekonomiczna w Poznaniu, 1997.

[18] Michalski R., Klaus O., Tilipałow W.: Procesy naprawy maszyn – teoria i praktyka. Olsztyn - Kaliningrad, 2002. ISBN 83-914011-5-4.

[19] Muzalewski A.: Koszty eksploatacji maszyn. Warszawa: IBMER, 2003.

[20] Salonen A., Deleryd M.: Cost of poor maintenance: A concept for maintenance performance improvement. Journal of Quality in Maintenance Engineering, 2011, 17(1), 63-73.

[21] Selvika J.T., Avenb T.: A framework for reliability and risk centered maintenance. Reliability Engineering & System Safety, 2011, 96(2), 324-331.

[22] Rzeźnik C.: Podstawy obsługi technicznej maszyn rolniczych. Poznań, 2002. ISBN 83-7160-265-0.

[23] Sharma A., Yadava G.S., Deshmukh S.G.: A literature review and future perspectives on maintenance optimization. Journal of Quality in Maintenance Engineering, 2011, 17(1), 5-25.

[24] Tan C.M., Raghavan N.: A framework to practical predictive maintenance modelling for multi-state systems. Reliability Engineering and System Safety, 2008, 93(8), 1138-1150.

[25] Tomczyk W.: Problemy jakości w procesie eksploatacji i odnowy maszyn i urządzeń. Problemy jakości, 2006, 10. ISSN 0137-8651.

[26] Tomczyk W.: Obsługi techniczne w procesie odnowy i utrzymania maszyn i urządzeń rolniczych. Inżynieria Rolnicza, 2009, 6(115), 301-307. ISSN 1429-7264.

[27] Uzdowski M., Bramek K., Garczyński K.: Eksploatacja techniczna i naprawa. Warszawa: WKiŁ, 2003. ISBN 83-206-1496-1.

[28] Wang H.: A survey of maintenance policies of deteriorating systems. European Journal of Operational Research, 2002, 139(3), 469-489.