14. *Дынкин Е. Б.* Марковские процессы / *Е. Б. Дынкин*. – М.: Физматгиз, 1963. – 859 с.
15. *Бойчук А. А.* Обобщенно-обратные операторы и нетеровы краевые задачи / *А. А. Бойчук, В. Ф. Журавлев, А. М. Самойленко*. – К.: Наукова думка, 1994. – 315 с.

Аннотация. *В статье продемонстрировано применение методологии исследования непрерывных цепей Маркова для прогнозирования поведения системы «механизатор-машинно-тракторный агрегат-окружающая среда» и оценки риска травмирования трактористов-машинистов (механизаторов) АПК.*
Ключевые слова: *методы анализа производственного травматизма, непрерывные цепи Маркова, профессиональный риск трактористов-машинистов*

Annotation. *The paper demonstrated the use of continuous research methodology Markov chains to predict system behavior «mechanic-machine-tractor-unit-environment» and the risk of injury assessment tractor-drivers (machanizators) AIC.*
Key words: *methods for analyzing injuries, continuous Markov chains, professional tractor-risk drivers*

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PHYSICAL AND MATHEMATICAL MODELING OF TRIBOSYSTEM “WORKING TOOL – LAND”

Borak Konstantin
Zhytomyr Agrarian and Technical College

Annotation. *The work presents the results of physical and mathematical modeling of tribology system "working toll – land". We dealt with the processes that occur in dynamic state in tribology system and tasks for further researches.*
Key words: *tribosystem, physical and mathematical model, working tools, land*

Introduction. As a result of abrasive wear loss of the national product in developed countries ranges from 1 to 4% [1]. In agriculture complex working bodies of tillage machines are mostly exposed to wear. Ensuring reliability of these machines by improving the wear resistance is one of the major challenges of modern engineering.

The current stage of technological development is characterized by the use of wear-resistant materials, local hardening, heat treatment and other methods aimed to increase wear resistance of tillage machines. In these conditions, conventional methods of research of wear process are unacceptable, as working lives reach quite high values (e.g. for disk working bodies up to 3...4 years).

In tribology, in order to describe friction and wear processes in knots and mechanisms, the notion of tribosystem (TS) is used. As we know from work [2] TS is a complex thermodynamic system, which is formed by the interaction of rubbing bodies and interim environment. In tribology system occur many complex processes whose analysis is convenient to provide using the physical and mathematical model. The processes taking place in the tribology system, may be described by variables, which in general depend on the spatial coordinates and time and characterized by physical condition of TS [3].

To investigate the mechanism of wear of the friction surface in tribology system at different stages, it is necessary to use models that can provide the vulnerabilities of the system without long bench or operational research.

Main of research. Purpose of the research is analysis of tribology system "working tool – land".

An essential feature of any model is the degree of completeness of similarity of model with the object model. On this basis, all models can be divided into isomorphic and homomorphic. When modeling complex tribology systems, isomorphic models should be used, as such models include all the original characteristics of the object and can, in fact, replace it.

Physical and mathematical modeling of tribology system "working tool – land" should be carried out to identify the functional dependence of tribology process:

$$I = f(V, p, E, H_m, L, G_з, A, K_ф, P(\Delta H), C_V, W, Ha, P_г, \Psi, f), \quad (1)$$

where: I – Intensity of wear of the working tool of tillage machines, m^3/m; E – modul of elasticity of the material of the working body, H/m^2, f – coefficient of friction; V – velocity of the working body relative to ground m/s, p – pressure on the surface of the body N/m; N_m – micro hardness of the surface of the body, Pa; L – way of friction, m; G_3 – degree of consolidation of abrasive particles; $P(\Delta H)$ – probability of impact loading occurrence; C_V – the percentage of silica sand in the soil (mechanical soil texture); Ψ – soil acidity; W - soil moisture,%; H_a – micro hardness of abrasive; $P_г$ – soil hardness, kg/m^2; A – the average size of the abrasive particles, m; $K_ф$ –coefficient of abrasive particles form:

If case of tribology system "working tool – land", it consists of the components presented in Fig. 1.

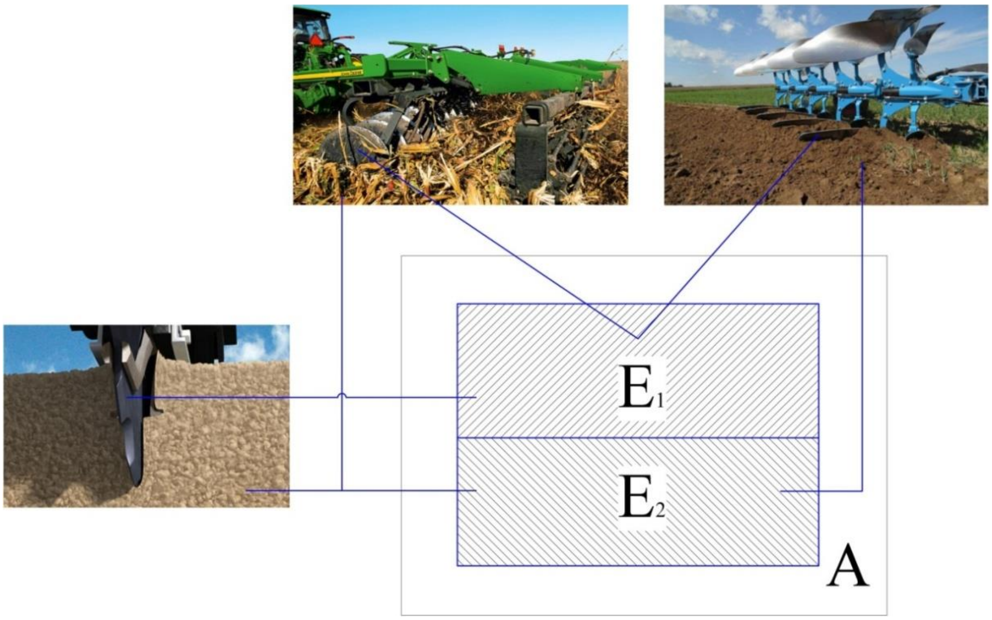

Fig. 1. Tribology system and tribology model: *A* – the environment; E_1 – working tool of tillage machines, E_2 – land.

It is known from work [3], that properties of details of tribology systems influence its structure, in our case tribology system components differ significantly in their properties.

Features of tribology system "working tool - land":

1) Mass wear is characteristic to one element of the system (working took);

2) An intermediate environment may appear on the second element (land) at certain humidity;

3) Soil as part of tribology system is heterogeneous and consists of many components (physical sand, natural clay, plant matter, living organisms, air, water, salts, and acids). Each of these elements differently affects the intensity of wear of working body.

4) In some cases this tribology system should be divided into two subsystems, since the mechanisms of wear on different surfaces of the body will be different (depending on the degree of consolidation of abrasive in soil, which interacts with the surface of the working tool).

As shown in tribology model, the interaction of two bodies E_1 and E_2 is without lubricant, but as noted in work [4], on clay and loamy soils with moisture reaching the limit, water appears on the contact surface, which acts as a lubricant. This is submitted by the experimental results (Figure 2), as seen, coefficient of friction significantly reduced for sandy soil with a moisture content of 20%, for heavy loam and clay soils - 30%. At this moisture level it is not possible to carry out manufacturing operations because farming equipment requirements cannot be executed, so we will not work with the tribology system with lubricant (water).

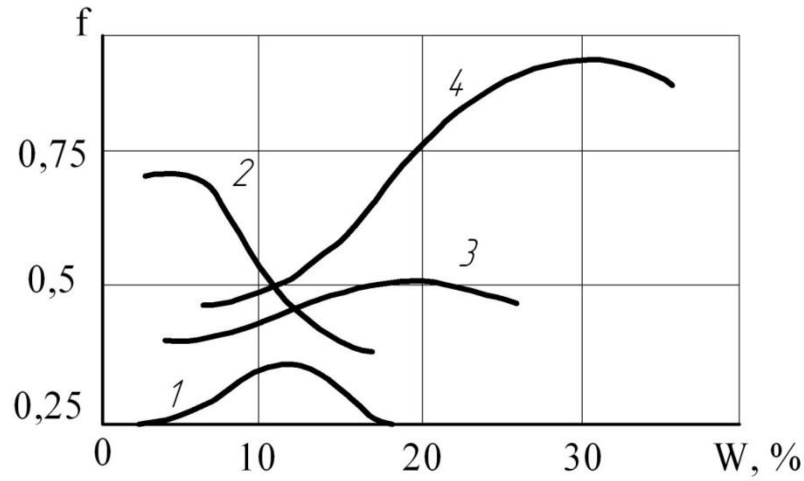

Fig. 2. Change of friction coefficient *f* of soil on steel depending on humidity: 1 – sandy soil, 2 – sandy bound soil, 3 – medium loam, 4 – heavy loam and clay.

In the interaction components of TS exercise mutual influence. This interaction will vary depending on the static or dynamic condition of tribology system. TS "working tool - land" only occurs in a dynamic state, so there is no need to consider it in a static state. The processes that occur in a dynamic state are shown in Fig. 3.

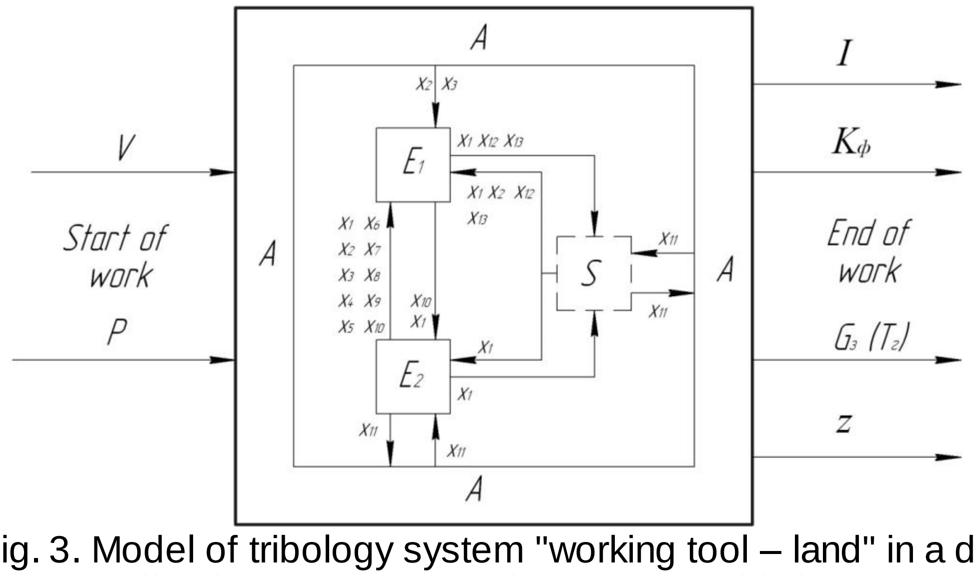

Fig. 3. Model of tribology system "working tool – land" in a dynamic state: x_1 – adhesion; x_2 – corrosion; x_3 – oxidation; x_4 – elastic deformation; x_5 – plastic deformation; x_6 – micro cutting; x_7 – scratching; x_8 – tearing; x_9 – the destruction of the friction surface; x_{10} – phase and structural changes; x_{11} – diffusion; x_{12} – adsorption; x_{13} – chemisorption; *V* – the relative speed of movement; *P* – pressure on the friction surface; I – intensity of wear; G_3 – The degree of consolidation of abrasive particles; $P_г$ – hardness of the soil; $K_ф$ – coefficient of abrasive particles form; *z* – related processes; *A* – the environment; E_1, E_2 – elements of the system; *S* – lubricant (water).

The access to tribology system includes such related processes (z), as slander of surface of friction, aging, thermomechanical, electrical and other [7].

Apparently the biggest influence in tribology system exposed element 1 (working body of tillage machine) on the part of element 2 (soil). Intensity of these processes depends on the input characteristics (*V, P*) and the initial state of the system.

The purpose of existence of tribology system "working tool - land" at a fundamental level can be considered as a transformation $\{X\} \xrightarrow{T} \{Y\}$. The main input (*X*) in tribology system is movement and the work performed by the element E_1, the main output is the structure of element E_1. In the real conditions, we get a lot of other output values that are adverse and undesirable in most cases.

In work [8] it is known that the energy balance of tribology system may be presented in form of dependence:

$$\sum E_x = \sum E_y + \sum E_z + \sum E_s + \sum E_t, \qquad (3)$$

where: E_x – supplied energy; E_y – useful energy (for tribology system "working tool - land" useful energy is spent on the structure of element E2); E_Z – the losses of the system; E_S – energy storage (deformation); *Et* – warmness, obtained from mechanical energy.

The heat that is released by the interaction of element E_1 with element E_2 dissipates fairly quickly in the second element, due to its relatively large volumes compared to the first element and a significant temperature difference with the environment.

Since only one element of tribology system is subjected to mass wear, then we can write the mass balance with the help of the following equation:

$$\sum m = \left(\sum m_{E1} - \sum m_{1a} - \sum m_{1c} \right) + \left(\sum m_{E2} + \sum m_{1a} + \sum m_{1c} \right), \qquad (4)$$

where: m – mass of tribology system; m_{E1} – mass of element E_1 before the work performance; m_{1a} – mass of material of element E_1, which is transferred to the element E_2 during the work performance; m_{1c} – mass of all products of the chemical reaction of element E_1, which is transferred to the element E_2 during the work performance; m_{E2} – mass of element E_2 before the start of work.

Sum $\left(\sum m_{1a} + \sum m_{1c} \right)$ characterizes the intensity of wear and depends on the conditions of the system (*V, p*), the properties of the element E_1 (E, N_m, chemical composition of the material) properties of the element E_2 (G_3 A, $K_ф$, P (ΔH), C_V, W, N_a, $P_г$, Ψ), the coefficient of friction of material of element E_1 on element E_2 (*f*) and by way of friction (*L*). In most cases tribologists try to unilaterally solve the problem of reducing the wear rate by improving the working surface properties of the element

E_1. In fact, to solve this problem, allowing to fully use the potential of the element E_1, you must use a systematic approach to analyze tribology system "working tool – land".

First attempt of system analysis in tribology were made by H. Czichos in his work «Tribology – a system approach to science and technology of friction, lubrication and wear» (in the post-soviet countries, due to incorrect translation, this work is known as "Systematic analysis in tribonik") [7].

Prior systematic analysis of tribology systems may not be fully applied to tribology system "working tool - land" because, as noted above, it has specific characteristics that do not allow it to completely fall within the classification proposed by H. Czichos [7].

To conduct a systematic analysis of tribology system "working tool - land", one shall follow these steps:

- build physical and mathematical model of tribology system in the dynamic and static state that can objectively describe all phenomena, processes and sub processes taking place in tribology system;
- make a phenomenological model of the processes taking place in the tribology system;
- to analyze the properties of individual components and aggregate properties of tribology system;
- mathematically describe the functional transformation of input variables x in the output y;
- identify the main criteria for the efficient functioning of tribology system "working tool – land", its limits and operating conditions.

The use of a systematic approach to problem solving in modeling tribology system "working tool – land" will enable:

- provide the synthesis of knowledge from different sciences (physics, chemistry, mathematics, tribology systems theory, management theory, material science, soil science, etc.);
- significantly reduce the time for laboratory, bench and operational researches for making objective decisions to improve wear resistance parts of tribology system.

Conclusions. Further investigation of tribology system "working tool – land" should be targeted to the establishment of functional dependence of tribology process with synthesis of all knowledge related sciences.

References

1. *Кіндрачук М. В.* Трибологія: підручник / *М. В. Кіндрачук, В. Ф. Лабунець, М. І. Пашечко, Є. В. Корбут*. – К.: НАУ-друк, 2009. – 392 с.

2. *Словарь*-справочник по трению, износу и смазке деталей машин [Текст] : словарь / [*В. Д. Зозуля* и др.] ; отв. ред. *И. М. Федорченко* ; Ин-т проблем материаловедения АН УССР. – 2-е изд., перераб. и доп. – К. : Наукова. думка, 1990. – 258 с.

3. *Носко А. Л.* Математическое моделирование трибологических систем (применительно к тормозным устройствам ПТМ) / *А. Л. Носко* // Вестник МГТУ им. Н. Э. Баумана. Машиностроение. – 2006. – № 1. – С. 83–98.
4. *Синеоков Г. Н.* Теория и расчетпочвообрабатывающих машин / *Г. Н. Синеоков, И. М. Панов*. – М.: Машиностроение, 1977. – 328 с.
5. *Тененбаум М. М.* Износостойкость конструкционных материалов и деталей машин / *М. М. Тененбаун*. – М.: Машиностроение, 1966. – 332 с.
6. *Дворук В. І.* Трібофізика / *В. І. Дворук, В. А. Войтов*. – Х.: ФЛП Томенко Ю.І., 2014. – 374 с.
7. *Чихос Х.* Системный анализ в трибонике. A Systems Approachto the Science and Technology of Friction, Lubrication and Wear: монография / *Х. Чихос* ; пер. *С. А. Харламов*; ст. науч. ред. *О. Н. Вишнякова*; мл. науч. ред. *Е. П. Орлова*. – М.: Мир, 1982. – 351 с.
8. *Справочник* по триботехнике / Под общ. ред. *М. Хебты*, *А. В. Чичинадзе*. В 3 т. Т. 1. Теоретические основы. – М.: Машиностроение, 1989. – 400 с.

Анотація. *Приведено результати фізико-математичного моделювання трибосистеми «робочий орган – ґрунт». Розглянуто процеси,що відбуваються в динамічному стані трибосистеми та поставлено завдання для подальших досліджень.*

Ключові слова: *трибосистеми, фізико-математична модель, робочі органи, грунт*

Аннотация. *Приведены результаты физико-математического моделирования трибосистемы «рабочий орган – почва». Рассмотрены процессы, происходящие в динамическом состоянии трибосистемы и поставлена задача для дальнейших исследований.*

Ключевые слова: *трибосистемы, физико-математическая модель, рабочие органы, почва*

УДК 693.542.52-868

ДОСЛІДЖЕННЯ ПОЛІЧАСТОТНОГО РЕЖИМУ КОЛИВАНЬ ЕЛЕКТРОМАГНІТНОЇ УДАРНО-ВІБРАЦІЙНОЇ СИСТЕМИ

В. А. Басараб, кандидат технічних наук
Київський національний університет будівництва і архітектури

Анотація. *В статті розглядається питання створення полічастотного режиму коливань робочого органу електромагнітної ударно-вібраційної установки для ущільнення*