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General approaches to system optimization for workflows of corn-harvesting machines

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Summary. The article covers the systematic basis for the creation of new technological processes of corn harvesting machines. Modern corn-harvesting machines have reached certain thresholds according to their technological properties that most significantly affect the final production and economic indicators of planting corn for grain efficiency, still they do not meet modern requirements. The technological properties mentioned above are hardly adjusted for wide range of physical and mechanical properties of the plants and crop parameters.

This situation is caused by new machine´s working parts being viewed by researchers and developers as complex technical systems not from the standpoint of general systems theory but in terms of the use of traditional knowledge of the laws of agricultural mechanics, thus not getting proper attention to their systematic coordination with working conditions.

Based on this, the paper presents a structural scheme for the system “mechanized corn for grain harvesting”, key elements of which are: agricultural (A), engineering (B) and selectional (C) supply. Interconnection of the subsystem´s elements and their consistency determine the effectiveness of the whole process. Inconsistency of the links A↔B and B↔C is observed. The conceptual system “mechanized corn for grain harvesting” design relates to the field with clear NO-factors: incompleteness, uncertainty, inconsistency and lack of information for decision making, thus it is important to review tasks of conceptual design from the most general constructual standpoint. The method of describing systems at the conceptual level is suggested.

This systematic representation of corn-harvesting machines allows to approach the task of their workflows modeling from the most general standpoint.

Key words: corn-harvesting machines, working parts, technological process, methods of system analysis, systems engineering and systems modeling.

INTRODUCTION

As stated above [1, 16. 17], modern corn-harvesting machines of both domestic and foreign origin have reached certain thresholds according to their technological properties that most significantly affect the final production and economic indicators of planting corn for grain efficiency, still they do not meet modern requirements. Another problem is the fact that these technological properties are hardly adjusted for reliable and qualitative performance of the process in a wide range of physical and mechanical properties of the plants, crop yields and parameters. It is caused by the design peculiarities of the machines´ main working parts, attempts for modernization of which (making partial changes in the design of cob-separating and cleaning organs in order to intensify their effect on stems and cobs) have not given the required increase of efficiency of technological process over the last two decades.

What has caused this situation? Why have obvious advantages and new possibilities for new design developments, that have been suggested until now, not given the required results and not improved significantly quality indicators of technological process? The point of this situation can be summarized as follows. Researchers and developers of new corn-harvesting machines´ working parts view them as complex technical systems not from the standpoint of general systems theory [2] but in terms of the use of traditional knowledge of the laws of agricultural mechanics, therefore the required attention is not given to their systematic coordination with working conditions, agrobiological characteristics of corn plants, the intended purpose of the harvesting, during substantiation of the main technological and constructional parameters.

Methods of system modeling are widely used in the design of modern samples of aviation and space technology and other advanced fields of mechanical engineering. This scientific approach is connected to the study of methodological and scientific bases of modeling a broad class of complex systems as the stage of their research and design. The subject of the analyzed scientific approach is the study of the general laws of selection and substantiation of the system model, realization of computing experiments on the model, processing and interpretation of their results [3, 4, 5].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Successful development of methods of system analysis, theory of technical and technological systems has been achieved due to efforts of many scientists. It is not possible to make a full review of these theories, so let us pay attention only to some scholars. In the first place we should mention monograph edited by M.Z. Zhurovskyi [2], in which the basics of system analysis as an applied scientific methodology designed to study complex problems of different nature are given. New methods of system analysis and prediction of the development of complex technological and engineering systems are shown in studies [6, 7, 8, 9]. Studies [10-12, 20] are devoted to solving complex problems of development of methods of synthesis of technological processes and systems of new generation on the basis of system optimization. It should be mentioned though that objects in research of this works are engineering technological processes, automated conveyors and rotary lines, metalworking machine tools numerically controlled.

Scientific and methodological foundations of research of social agro-industrial systems and their functional structures, substantiation of system efficiency of the modern machinery were developed by O.V. Sydorchuk, who has established a new scientific approach - system and technological bases of modeling, forecasting efficiency, development management of machine-functional structures of agricultural production [13, 14]. Certain approaches for designing of scientific and methodological principles of the structure formation and the creation of highly efficient combined tillage machines are given in studies [15].

It should be noted that These and some other studies mainly cover consolidated phases of systems analysis and scientific and methodological principles of system approach to solving the problems of machinery design, which are common for most complex technical objects. However, during their detailed elaboration it is necessary to consider objects´ peculiarities and specificity of system analysis which is conditioned by them.

OBJECTIVES

The article is aiming at forming system basis for the creation of new technological processes of corn-for-grain harvesting machines.

THE MAIN RESULTS OF THE RESEARCH

Currently systemology is an area of knowledge in which tasks of description, research and design of systems in various subject areas are studied from the point of detection invariants in them [11]. Since the conceptual system design, especially complex systems such as "mechanized corn-for-grain harvesting" (fig. 1), is related to the field with clear NO-factors: incompleteness, uncertainty, inconsistency and lack of information for decision making, thus it is important to review tasks of conceptual design from the most general constructual standpoint.

According to the structural scheme (fig.1.), main elements of the system "mechanized corn for grain harvesting" are: agricultural (A), engineering (B) and selectional (C) supply. Interconnection of the subsystem´s elements and their consistency determine the effectiveness of the whole process.

Elementary analysis of the current situation allows to make a conclusion of the B↔C links inconsistency.

Varieties breeding specifically for mechanical harvesting does not attempt to get cobs with shape index close to 1, equally sized, with an extended range of cobs dynamic interaction with cob-separating and cleaning organs, as well as the same time of cobs ripening. It should be noted that this is the most inert part of the system, as it takes several cultivation cycles for breeding research, thus mechanization level is maintained in this period.

A↔B links connection is more close and mobile.

Quality of the mechanical corn harvesting can be annually maintained through compliance with the necessary agro technical requirements for all the technological operations of corn for grain cultivation.

It is also practically important to establish permissible deviations in providing determined quality of production, as the final quality can be measured by comparing overall costs to the optimal costs in each system link.

Among the known methods of system description at the conceptual level, which are orientated on computer implementation, a description given in [3] is the most reasonable. It has following levels with the corresponding main tasks:

- selection or initiation of the main efficient function of the system or the main need of society that is satisfied with the system;
- selection or initiation of the functional system structures;
- selection or initiation of the system operating principle;
- selection or initiation of the technical solution;
- selection or initiation of the system operating principle;
- selection or initiation parametric solution.

Accordingly, it is expedient to give basic definitions. *Functional structure* – is a set of system elements and their functions that define the structure and algorithm of the system functioning. *Operating principle (OP)* – is a set of phenomena at lower hierarchical levels that determine the flow of processes in the system and cause the external system properties. *Technical solution (TS)* - is a qualitative description of the system with indicating technological and constructive design (in the broad sense of these concepts), together with algorithm of functioning. *Parametric solution (PS)* – is a full description of the system with definition of quantitative technological and structural parameters.

When it comes to methods for systems engineering and system modeling for research of technological processes and structural elements of corn-harvesting machines (CHM) as the main component of the system (fig.1), it is expedient to allocate them as a separate structural unit of the classification scheme of agricultural combine harvesters, as their workflows have some fundamental differences and peculiarities.

Firstly, CHM – is a class of agricultural machines, primary purpose of which is mechanical destruction of corn plant elements connections (stems with rhizomes, cobs with stems, husk with cobs, grains with cobs) for their further separation and use on the intended purpose.

CHM can be divided in two subclasses according to their function. Subclass-1 includes machines for harvesting corn on the cobs with simultaneous peeling of the husks, such as trailed and self-propelled machines. Subclass-2 includes corn harvesting machines with simultaneous cob treshing, such as hinged reaper for combine harvesters.

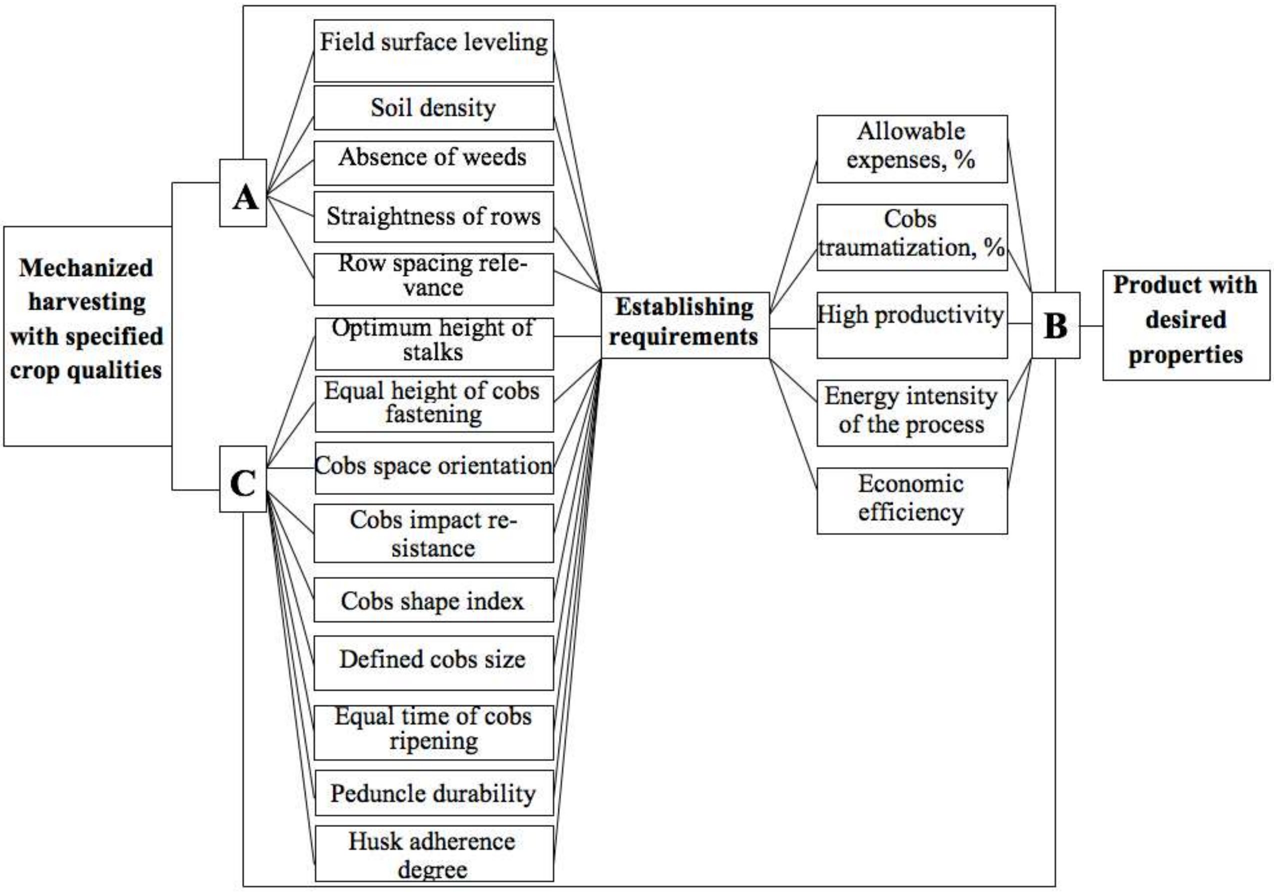

Fig. 1. Structural scheme for the system "mechanized corn for grain harvesting"

A separate subclass of CHM includes stationary machines for postharvest crop processing (not treshed cobs and grain), but we don't consider them as they have their own specific peculiarities.

Despite the diversity of purposes and constructions all the CHM share a common object of destruction - corn plants and their components, process of mechanical destruction of which can be considered as multifactorial complex system [1, 18]. Different machines implement in one degree or another such known types of mechanical destruction, [1, 19]: stretching, cutting, twisting, vibration, kicking, grinding. All the different destruction methods of corn plants and their components have two fundamental features: cyclicity and stochastic nature. These features largely determine the dynamic nature of loads which machine working organs are overcoming. Therefore, issues of optimizing dynamic properties and reducing dynamic loads are relevant for all the CHM. It mainly concerns cobs and grains, for which load limitation that cause their damage is important.

Main components of the technological process of destruction of corn plant connections of CHM are: 1 – separation of stems from rhizomes; 2 – separation cobs from stems; 3 – separation of husks from cobs; 4 – separation grains from cobs; 5 – removing the final product from destructing areas. Machines of subclass-1 have four-staged destructing process (the 4^{th} component is absent), where separating cobs from stems and damaging husks are inextricably linked. Machines of subclass-2 don't have the third component of the destructing process.

While removing the final product from destructing areas plant components may be partly damaged, though this factor is not primary and is the subject of the research, which is aimed at achieving minimal impact on the final quality of the technological process.

During study of CHM structure, principles of structuring and integrity, qualitative conversions [21] can be made predicting appearance of machines with new qualitative characteristics, able to expand their technological capabilities and qualitative indicators of work.

The proposed theory of complex machinery is based on the partial and whole categories, which is expressed by the ratio between the set of elements of these devices and links that connect these elements and lead to the emergence of integrative properties and regularities not specific to individual elements. Due to this interrelation appears "a whole" - CHM, individual elements being components of which. Therefore, CHM structure should be considered in the most general form that expresses structure and inner form of organization of these shafts, which serve as stable interconnections between its elements, as well laws of these interconnections.

Graph of the CHM subclass-1 connections can be seen in fig. 2.

It is marked:

E_1 - group of elements characterizing the plant mass:

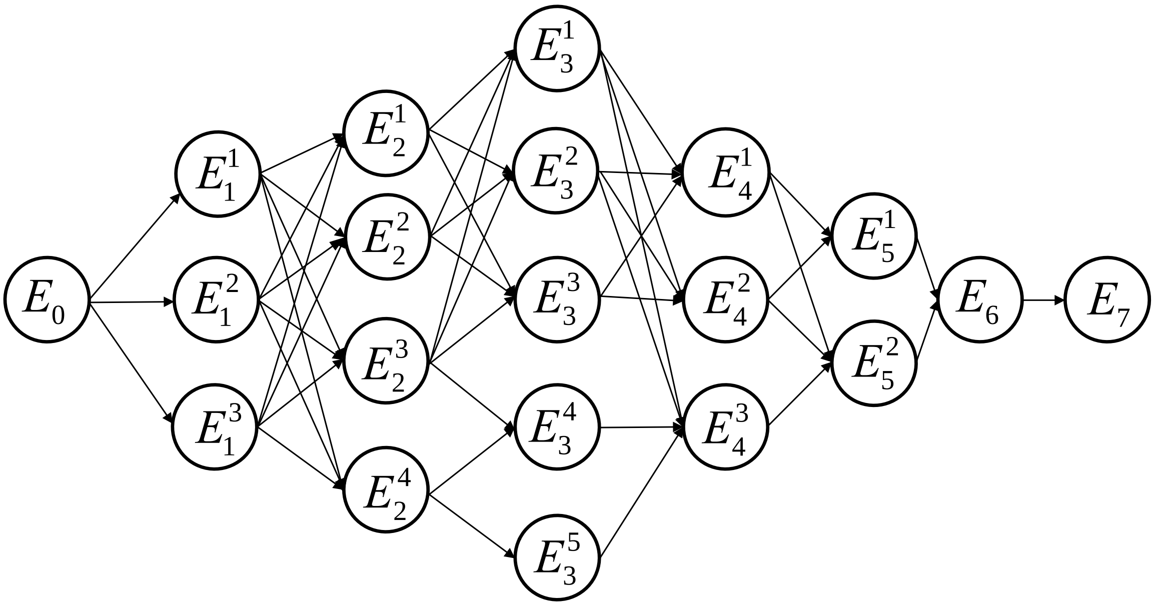

Fig. 2. Graph of the CHM subclass-1 connections

E_1^1 - stems density; E_1^2 - height of fastening corncobs on stems; E_1^3 - size-mass characteristics of cobs;

E_2 - group characterizing way of delivering plants in the work area: E_2^1 - random delivery; E_2^2 - delivery with spiral cones; E_2^3 - delivery with active stems separator; E_2^4 - delivery with conveyor-orientator;

E_3 - group that characterizes a type of cob-separating system: E_3^1 - with two conveying rollers and two passive horizontal stripping plates; E_3^2 - with two conveying rollers and two active horizontal stripping plates; E_3^3 - with two conveying rollers and two stripping plates mounted on different planes; E_3^4 - three-roller system with two active conveying rollers; E_3^5 - two-roller system with two active rollers that combine functions of conveying and separating cobs;

E_4 - group that characterizes additional elements above the cob-separating machine; E_4^2 - elements that create extra effort for destructing connections of "stem-cob" and "cob-husk"; E_4^3 - without additional elements;

E_5 - group that characterizes a destruction of husks degree in the separating area: E_5^1 - high destruction degree; E_5^2 - low destruction degree;

E_6 - deviation of mechanisms regulatory parameters;

E_7 - the difference in crop parameters characterizing its quality.

The performed morphological analysis arising from the regularities of CHM structure, has allowed to create new partial solutions that are implemented in specific types of cob-separating systems [1, 19]. The proposed theory represents a system of basic characteristics and rules of their combination, that allows to obtain machines with new properties using logic synthesis.

From the energy point of view for all the CHM, according to our researches [17], processes of destruction of connections between elements of corn plants play a dominant role, it provides a basis for developing common approaches to modeling workflows of different types of CHM.

From the point of view of systems engineering of CHM technological processes modeling, we should start with a common system model which establishes a connection between the vectors of input effects X(t), output processes Y(t) and a condition vector S(t). The process of the system functioning is described by an output equation (1) and a condition equation (2):

$$Y(t) = Q\left(X_{t_0 t_1}, S(t_0)\right); \tag{1}$$

$$S(t) = H\left(X_{t_0 t_1}, S(t_0)\right). \tag{2}$$

where: $X_{t_0 t_1}$ - is an input effect fragment limited by time points t0 and t1;

Q – is an outputs operator which uniquely identifies an output process depending on an input effect and an initial condition;

H – is a transition operator that establishes a definite dependence of the system condition at any time point from the interval [t0, t1] on an initial condition and an input effect fragment.

An important role during a CHM model synthesis plays substantiation of a time interval of the modeling. Its value depends on the purposes of the modeling, and largely determines the specific task of interpretation of such system-wide notions as input and output effects and condition. The minimum time interval of CHM functioning can be estimated by a $10^{-2}\ldots10^{-3}$s value. It is determined by the occurrence time of the maximum peak loads during overloading and jamming of a specific working body. The biggest time interval equals a machine resource and has a $10^{2}\ldots10^{3}$h value. Therefore, different models should be used in order to study the system functioning in a large scatter of time slots.

Input effects for CHM modeling in general case are parameters and operating modes of working bodies as well as managing exposure of human operator. Output processes are seen as (fig. 1): machine performance, level of crop losses, degree of grains and cobs traumatization, together with loads in power subsystems, determining the reliability of CHM and power consumption of their operation process. Components of the CHM condition vector are deterioration indicators of working bodies and power subsystems actuators, compliance of adjusting parameters with the conditions of work.

CHM modeling peculiarity is a necessity to include parameters of the A↔B i B↔C links (fig. 1) to the condition vector´s components, which is known to significantly affect the efficiency of the system functioning.

After defining of a common system model (1) and (2), in order to specificate it, it is necessary to consider CHM in terms of system properties such as continuity, linearity, stationarity and stochasticity. In general, CHM must be seen as continuous, nonlinear, non-stationary, stochastic system.

Continuity of CHM as a technical system in time is caused by the inability to instantaneously change condition parameters. But in some cases in order to simplify the model it is expedient to make an assumption of instantaneous change of these parameters. An example of such an assumption can be a model of supply (supplying of plants) of machine working bodies.

Continuity of the dynamic characteristics of CHM in space can be neglected in most cases. These characteristics can be seen then as dynamic systems with concentrated parameters. The validity of this assumption is confirmed by numerous studies of CHM dynamics [1, 17].

When it comes to linearity, CHM must be seen as nonlinear system in most cases. It is caused by nonlinearity of the dynamic characteristics of CHM which has nonlinear parts (motor, safety devices, elastic couplings), as well as nonlinear nature of interactions between CHM working bodies with corn plants elements.

Nonstationarity of CHM in a general system meaning is reflected in the fact that characteristics of the system functioning process depend on the choice of a temporary fragment from the total period of its operation. With increased duration of the operation, deterioration of machine elements and dynamic loads in its units are also increased, as well as reliability indexes are decreased. On the other hand, a concept of stationary is widely used in terms of stochastic processes theory during studies of CHM. At the same time, stochastic processes in power subsystems of CHM in constant modes of operation are considered as stationary. A significant role in CHM functioning play transitional modes (starting, braking, etc.), as well as their structural changes.

Stochasticity of the studied system is determined by a random nature of change of mechanical properties and a structure of the plant mass (stems shape and size, sizes and height of cobs, humidity of the mass, etc.), by a random change of patterns of interactions between working bodies and plant elements, by a random change of adjusting parameters during operation.

In a formalized form the task of optimum synthesis of CHM is to identify independent variables independent constructive and operational parameters) $X_1, X_2, \dots, X_n$, when an optimality criterion is a function of a goal of the studied CHM system, $-\Phi = F(X_1, X_2, \dots, X_n)$, which is a nonlinear function of variables, has the minimum (or maximum) possible value, provided that $X_1, X_2, \dots, X_n$ have only positive values, that is $X_j \geq 0;\ j = 1,2,\dots,n,$ and meet the limitations given in the form of inequalities for some, nonlinear in general, functions of these variables (limitation functions or design limitations) $R_i(X_1, X_2, \dots, X_n) \leq 0$ $(i=1,\dots,m,\ m \leq n$ and $m \geq n)$.

CONCLUSIONS

1. The proposed system conception of corn harvesting machines allows to approach the task of modeling of their workflows and to consciously formulate a possibility of gradual simplifying of models in dealing with specific scientific and engineering tasks.

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ОБЩИЕ ПОДХОДЫ К СИСТЕМНОЙ ОПТИМИЗАЦИИ РАБОЧИХ ПРОЦЕССОВ КУКУРУЗОУБОРОЧНЫХ МАШИН

Д. Кузенко, О. Крупич

Аннотация. В статье рассматриваются системные основы создания новых технологических процессов машин для уборки кукурузы на зерно. Современные кукурузоуборочные машины по своим технологическим свойствам, что наиболее существенно влияют на конечные производственно-экономические показатели эффективности віращивания кукурузы на зерно, достигли определенных предельных показателей, но не удовлетворяют современным требованиям. Упомянутые технологические характеристики почти не прспособлены к широкому диапазону физико-механических свойств растений и параметров посевов.

Причина такого положения в том, что ученые и разработчики новых рабочих органов кукурузоуборочных машин рассматривают их как сложные технические системы не с позиций общей теории систем, а с точки зрения использования традиционных знаний законов земледельческой механики, не предоставляется должного внимания их системному согласованию с условиями работы.

Исходя из этого, в работе предложена струк- турная схема системы «механизированная уборка кукурузы на зерно», основными элементами которой являются: агрономическое (А), инженерное (В) и селекционное (С) обеспечения. Взаимосвязь элементов этой подсистемы и их согласованность определяют эффективность технологического процесса в целом, отмечено несогласованность звеньев А↔В и В↔С. Концептуальное проектирование системы «механизированная уборка кукурузы на зерно», относится к области с интенсивно выраженными НЕ-факторами: неполнотой, неопределенностью, противоречивостью и недостаточностью информации для принятия решений, поэтому актуальным является рассмотрение задач концептуального проектирования с наиболее общих конструкционных позиций, предложен способ описания системы на концептуальном уровне.

Ключевые слова: кукурузоуборочные машины, рабочие органы, технологический процесс, методы системного анализа, системотехника и системное моделирование.