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METHODOLOGICAL ASPECTS OF CONCEPTUAL DESIGN OF AN AGRICULTURAL MACHINE BY THE CASE OF A TUNNEL SPRAYING MACHINE[1]

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ABSTRACT

The article presents the procedure of determination of a structural form of an agricultural machine which encompasses methodological aspects of design related to the division of the basic objective function into member functions, multi-variant solutions and synthesis of astructural form (a virtual prototype of an agricultural machine). The suggested course of proceeding was presented by the case of a design of a tunnel spraying machine. This example reflects well and includes the specificity of the design object in the form of an agricultural machine with specific technical and agro-technical requirements. Attention was paid to the aspects related to methodology of selection of fractional solutions based on previously defined criteria.

Introduction

A contemporary engineer prepared for creative shaping of a technical reality should be endowed with general methodical knowledge on the subject of design and with a detailed knowledge which includes specific issues of a defined field of technology. Standards of EFNEA (*European Federation of National Engineering Associations*) recommend that designing engineers should have the following skills: good problem formulation, use of modern tools and methods of designing and making various assessments often of contradictory factors (e.g. costs, quality, safety) in order to select the best technical solution. Some of the mentioned qualifications and skills are commonly required from engineers of all fields. (Coello, 2000). However, the scope of technical actions is so extensive that it is difficult to require designers to have universal knowledge and skills in designing technical means in each field of technique. Thus, a more detailed definition of designing canons which encompass the specificity of various branches is purposeful. Biosystem engineering is one of them. Particularly within the scope of machines which process biological material. Design of such machines should include the need of meeting specific requirements and restrictions

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related to the working process realization which are not popular in other branches of technique. An agricultural machine is some kind of a "mobile processing machine" but it usually works under non-defined conditions which result from a dynamic soil-machine-plant system. Therefore, standard rules applied in technical systems engineering should additionally include many aspects which refer directly to the biosystems engineering (Kośmicki et al., 2002; Pawłowski and Szczepaniak, 2005) and designing a farm machine should be qualified as a realization of complex engineering task.

Simple engineering tasks are generally solved with the use of typical designing methods (concerning foundations of machine construction. Complex engineering tasks will on the other hand refer to the technical system design which contains numerous components (function). They often have a considerable number of contradictory requirements (concerning e.g. soil compaction, reduction of plant damage, minimization of crop losses) and they are related both to the tasks of a specific engineering discipline and many other disciplines not only engineering ones. They are also "atypical" to a considerable extent (unique) and thus they do not have any prevailing method of solution. Their realization requires as a rule – a new approach - creative work oriented often a research one (Pawłowski et al., 2006, Talarczyk et al., 2015, Godyń et al., 2008). Solving a complex task sometimes has effects which are difficult to predict in a non-technical sphere (impact on safety, environment, specific requirements related to recycle etc.).

The approach which has been presented in this article orients a designer towards solving key issues as early as at the beginning of preparing a construction concept of a machine but it is assumed that design should be clearly process oriented – divergence of the problem and determination of the order in which particular fractional functions are performed is necessary (Pahl and Beitz, 1984; Ślipek, 1993). Therefore, formation of the functional structure of the designed technical mean and then development of solution variants for each function and selection of admissible solutions will be a main task in the course of preparing the conceptual design of an agricultural machine. Since, according to analyses, designers do not have problems with determination of single parts and elements of a construction but they have some difficulties with determination of relevant integration criteria and thus determination of an optimal structure of the entire technical system (Ślipek and Frączek, 2007; Ślipek et al., 2008). The objective of the presented research was to determine the complex design procedure which assumed a creative approach for determination of a structural form of an agricultural machine as a complex technical system encompassing at the same time technical and agro-technical requirements which distinguishes these machines from among other working machine group. Methodological aspects of design resulting from the analyses which were carried out were presented by the case of realization of a conceptual design of a tunnel spraying machine.

Methodology of design of a complex technical system

The presented design strategy is a functional strategy and is based on suggesting of some kind of a control list which consists in orienting a designer towards a creative approach to the process of determination of the machine structure and thus preventing omission of significant steps required in documentation of a design process. At such an assumption, a deisgn task should be formulated generally and may take the following wording – "To design a technical system whose objective function is .... (one should *determine the objective function*)".

It seems that such formulation of a problem may have a great heuristic power and should suggest some idealization of an activity of the designed technical mean. Therefore, on the initial stage of prototype formation meeting the requirements related to the production technology and reduction of production costs of the determined structure is not required. Since, encompassing these requirements could lead to premature rejection of a valuable, from a technical point of view, concept of the designed machine (including e.g. a new principle of operation, mechatronization of the process, innovation). In the suggested approach, it is assumed that requirements related to technological aspects of construction and profitability of production will be included only after a machine prototype is created.

A proposal of sample stages of the design process, which selects subsequent, logical tasks which are indispensable to be carried out by a designer/project team were given below. It may seem that such approach formalizes activities. However, it may prevent a "routine", often a superficial approach to solving technical problems. It has a fundamental meaning if we assume a requirement of creative solving of the project problem of the complex biotechnical system. Fig. 1 presents an algorithm including basic elements (steps) of the design process related to an information module (technology, technique, scientific research) which includes basic sources of knowledge indispensable for creating a concept of a machine and a tool module. The information module has a significant meaning for realization of the first three design modules (preparatory, decomposition and synthesis). On the other hand, a tool module is mainly used for realization of the following modules: decomposition, synthesis and structural. It does not mean, of course that "supporting" modules cannot be included on each stage.

The initial stage of the project assumes insight into the problem as result of which the problem will be specified and the objective function will be determined and recorded (step A). The problem of specification of design assumptions (step B) and determination of assessment criteria along with assignment of weights (step C) are significant in the presented design approach. The set of assumptions and criteria are determined before the functional analysis of the designed machine which causes that these sets are objectified. It allows elimination of possible premature suggestions and preferences concerning the concept of operation of a technical mean (Francik et al., 2014). On account of formal issues it is assumed that assumptions must be absolutely met by a designed machine. It must be emphasised that on this stage of design, in case of more complex and technical systems it is advantageous and even indispensable to use a selected decision support method. Detailed discussions related to methodological aspects of forming design requirements were described in the papers by the following authors (Ślipek and Frączek, 2007; Ślipek et al., 2008).

The following stage includes decomposition of the designed biotechnical system which comprises a functional analysis (step D) and then preparation of the structure card (step E). For the objective function which was determined and recorded in the A step, member functions, which must be carried out by a machine to achieve the assumed objective must be carried out. A functional structure must encompass a full working process which will be carried out by a machine.

When designing assumed technical biosystems including an appropriate order of realization of particular functions is required as a rule. For the assumed functional structure multi-variant concepts (separate for each fractional function) which present various ideas on the manner of functioning in a graphical form.

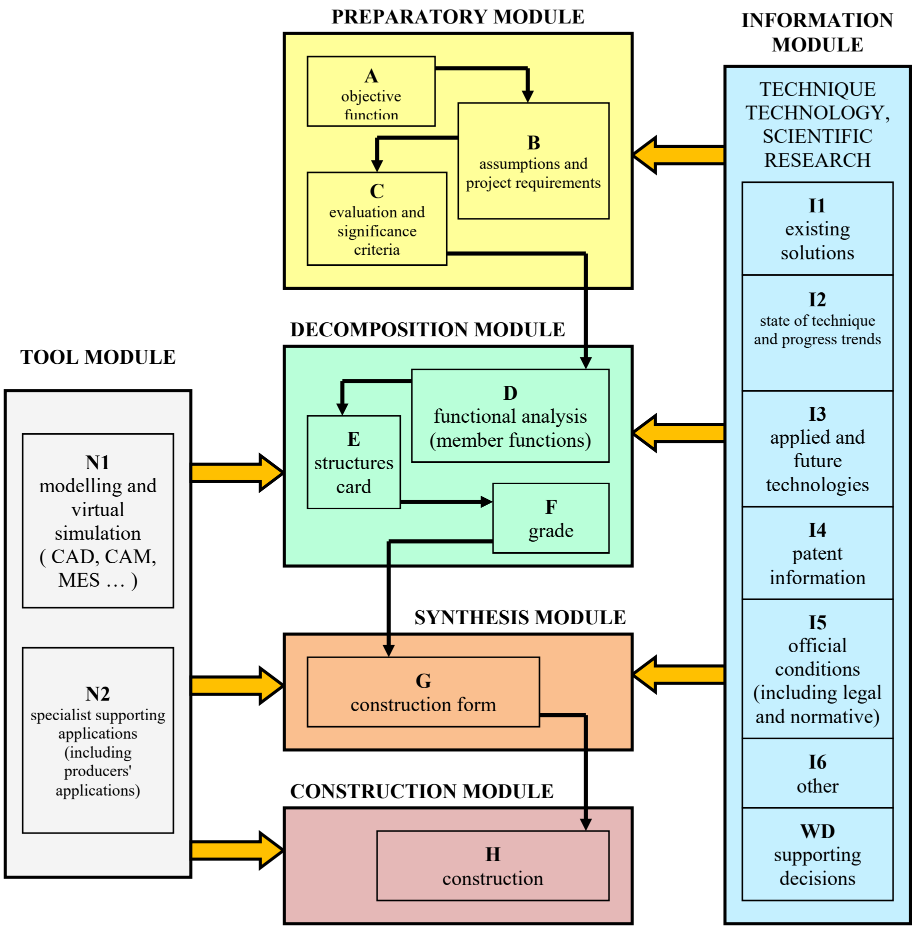

Figure 1. Design process algorithm

The concepts should be included in the set of admissible solutions adequate to the objective function of the designed biotechnical system. The set of created concepts may be presented in the form of the so-called structure card (step E). They are subjected to assessment based on the assumed criteria (step F). The task consists in calculating a point indicator P for each solution according to the following formula:

$$P = \sum_{i=1}^{n} W_i \cdot O_i \tag{1}$$

where:

- P – point indicator for a given variant of a solution,
- W_i – weight of i-criterion,
- O_i – point mark of i-criterion (e.g. in the scale 0-10 but the highest proves that criterion was met very well,
- n – number of criteria.

The synthesis of the structural form is the last stage of design of a biotechnical system (step G). On this stage creative assembly of elements (of a concept) of the machine structure is carried out with the assumption that for each member function a solution is selected which obtained the highest value of the point indicator. Any professional program for space modelling (3D) may be helpful for development of a synthesis of the structural form of a machine. As a result of these operations a virtual prototype of the entire machine is created which after tests and approval ends the conceptual designing procedure.

Further works carried out in a structural module have a routine nature and consist in carrying out standard calculations which lead to determination of structural properties: geometrical, material and dynamic according to construction principles.

Design procedure - example

The structure of the design process suggested in the previous chapter was illustrated on the example of a design of an orchard tunnel sprayer. Due to editorial reasons this example is not complete.

The design task is –To design an orchard sprayer whose objective function consists in regular distribution of water solution of an active substance in the form of droplets on the assimilation surface of fruit trees. Stages of the design process:

Step 1 – insight

When information on the methods of maintaining orchards, agrotechnical requirements, technical and exploitation parameters of sprayers, development trends, patents, innovations, provisions of law, harmonized standards was collected and analysed, it was decided that the object of the design will be a tunnel orchard sprayer.

Step 2 – determination of the list of assumptions and criteria

As a result of a detailed insight the most important design assumptions were formulated. Below their list was presented:

– Working speed at least 1.5 $m \cdot s^{-1}$,
– Control of width of operation of a working unit from 0.6 to 2.8 m,
– Control of height of operation of a working unit from 1 to 2.8 m,
– Maximum demand of power 75 kW,
– Capacity of a container for technological liquid 1500 l,
– Separate container for clear water with capacity of 15 l,
– Adjusted to moving on public roads,
– Single person operation,
– Simultaneous spraying of two rows of trees,
– Meeting safety and environmental protection requirements (machine directive 2006/42/EC, standards PN-EN 12761-1, PN-EN 907, ISO 10625).

Moreover, structural criteria were determined. Specification of criteria and weights was developed with Delphi method with the use of two rounds of tests (Matejun, 2012). They were grouped in 4 categories (along with the assigned weights W_i – sum of weights for all criteria is 100 points):

– General features of a structure	35 points.
high reliability	7 points
originality of a concept	5 points

structure compactness	6 points
low mass of a machine	4 points
susceptibility to mechatronization of working elements	6 points
simplicity of compactness	7 points
– Technological criteria	40 points
precision of spraying	13 points
regularity of spraying	11 points
usefulness in various conditions	6 points
high performance	4 points
maximum recovery of working liquid	6 points
– Economic criteria	15 points
low production cost	5 points
low exploitation cost	4 points
low energy consumption	6 points
– Ergonomic criteria	10 points
good visibility of working space	6 points
simplicity of operation	4 points

Step 3 – formulation of problem

Figure 2 presents the essence of the designed machine thus its objective function recorded with the use of "black box" (input-output).

Step 4 – determination of the functional structure of a machine

Example of such record was presented in figure 2 separating particular activities as separate elementary function (F1-F10).

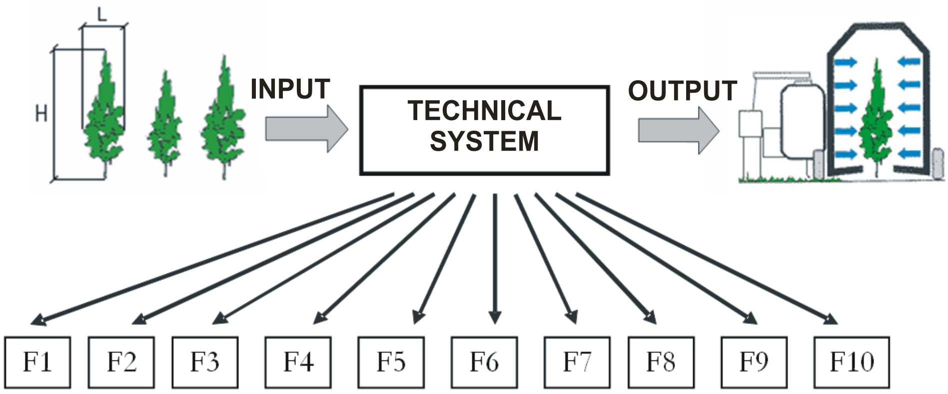

Figure 2. Formulation of a problem (record of the essence of operation and functional structure): F1 – manner of aggregation; F2 – sensor of tree crown width; F3 – sensor which detects spaces between trees and crown height; F4 – aggregating tunnels with a container; F5 – manner of recovery of non–used liquid; F6 – type of an indicator; F7 – method of liquid mixing in a container; F8 – drops distribution method; F9 – pump type; F10 – drops production method

Step 5 – card of structures

Figure 3 presents a card of structure including various options of solution (concepts) for each (among the determined in a previous step) elementary function.

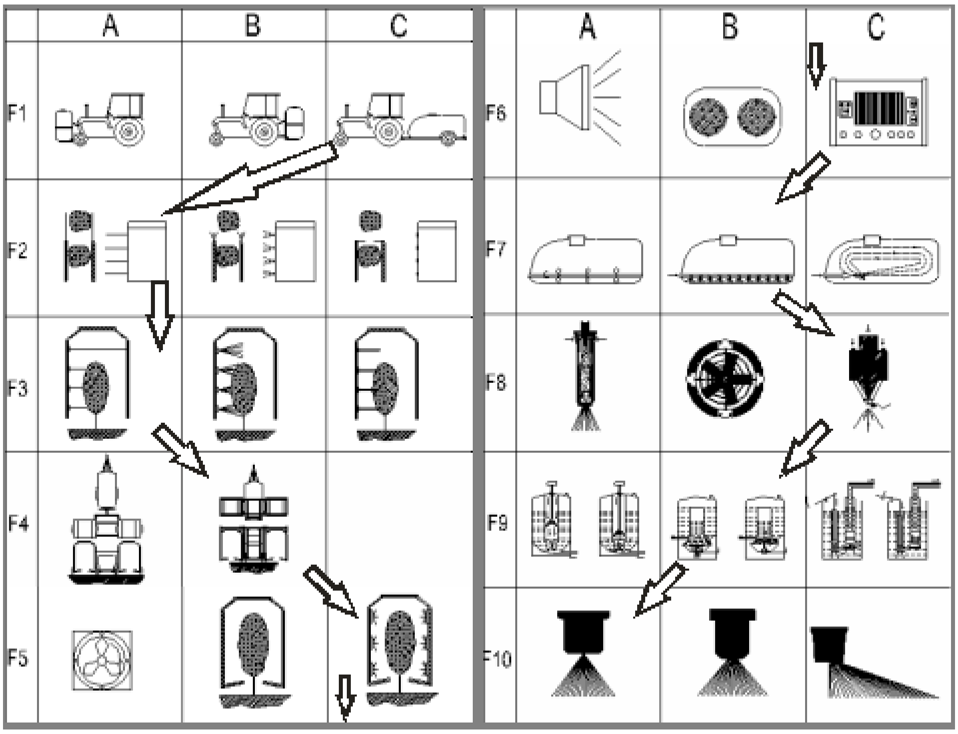

Figure 3. Card of structures (description of a function in figure 1): A,B,C – variants of solutions (arrows indicate the best solutions from the point of view of accepted criteria – table 1)

Step 4 - assessment of a concept

Table 1 presents average values of a point indicator P for particular variants of solutions from the card of structures (Fig. 3). These values were calculated based on the evaluation carried out separately by 10 experts. Figure 3 presents how variants, which obtained the highest average values of the point indicator were combined with the use of arrows.

Table 1.
Average values of a point indicator P for particular variants of solutions from the card of structures (figure 3).

Functions	Variants of solution		
	A	**B**	**C**
F1	518	511	609
F2	580	510	524
F3	662	585	590
F4	632	734	0
F5	468	654	735
F6	532	524	629
F7	418	560	501
F8	529	505	675
F9	466	545	464
F10	502	474	422

Step 7 – synthesis of the structural form

Figures 4, 5, 6 respectively show an example of the structure of the designed sprayer including for each elementary function a variant of a solution, which obtained the highest value of P indicators.

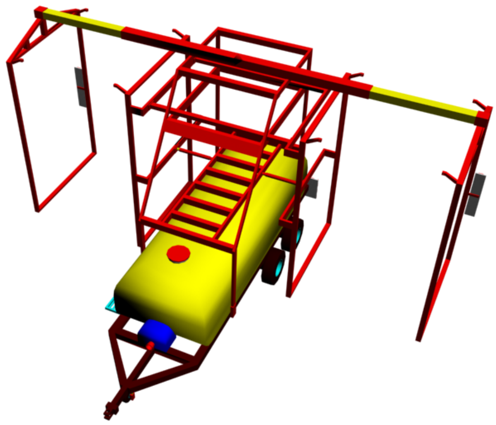

Figure 4. Structural concept of a load-bearing system (driving chassis and tunnel chassis)

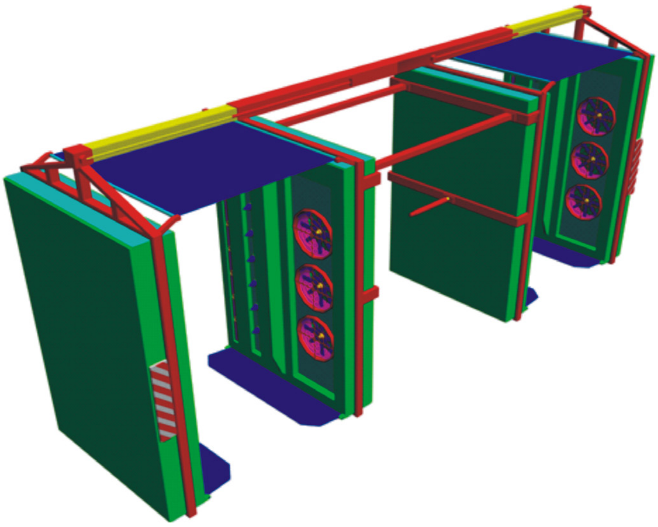

Figure 5. Enclosure of tunnel chassis

Figure 6. Final structural form of a tunnel sprayer – backview

Step 8 – determination of the structure for the created structural form of a sprayer

As a result of initial calculations which were carried out structural properties of the designed sprayer were determined. Figure 7 presents a simplified record of this structure.

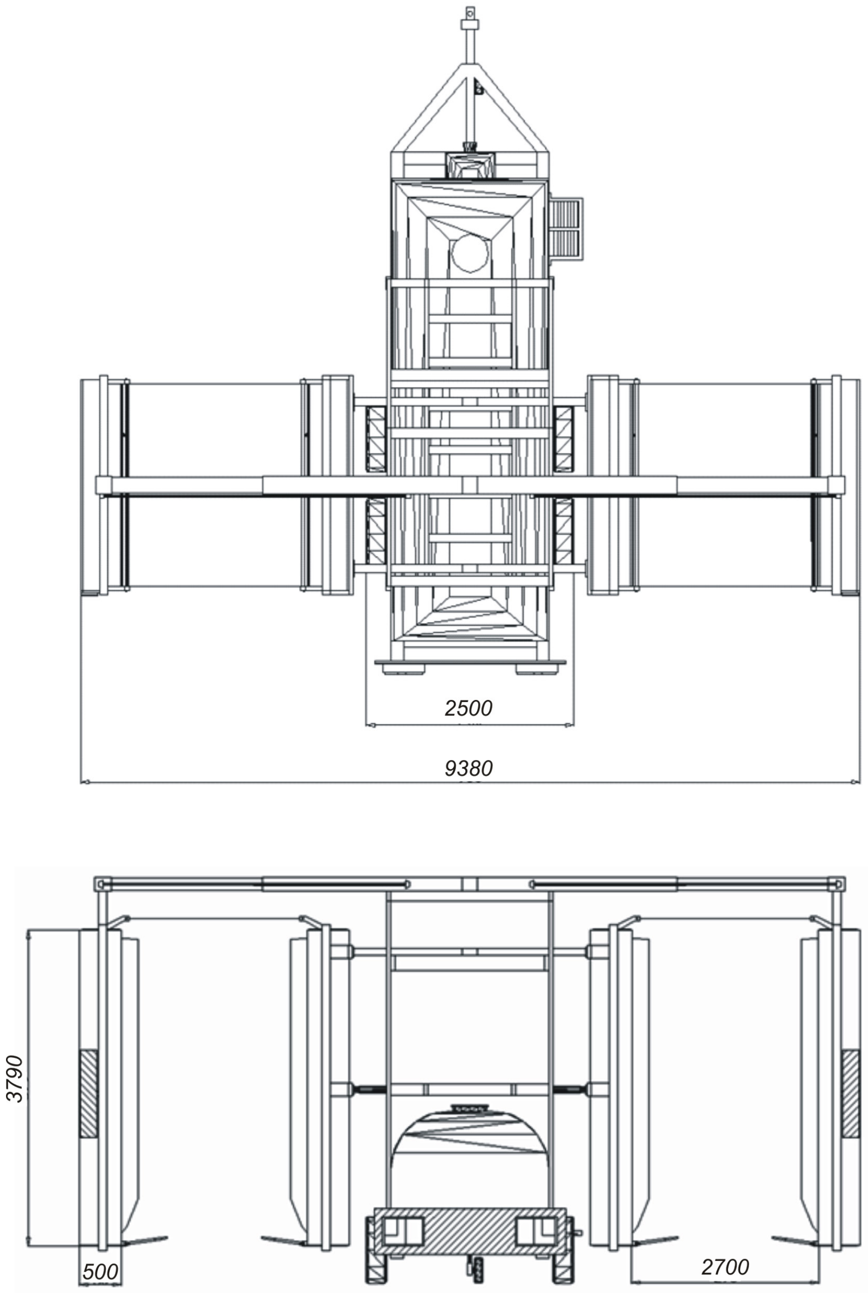

Figure 7. Record of the sprayer structure in projections

Conclusion

Qualifications and skills concerning formulation and solution of problems, setting requirements, taking up decisions are common for all engineers (Francik et al., 2014). Engineers who design agricultural machines often face a problem which results from their specificity, which locates an object of design in the soil-machine-plant system. Therefore, on the stage of design, a great attention should be paid to include technical, agrotechnical and non-technical requirements which result from operation of such a biotechnical system in the agricultural environment. The suggested procedure is based on the functional strategy of design and encompasses a multi-variant approach for the problem solving. Selection of the most favourable fractional solution takes place based on the well formulated requirements, in particular agrotechnical requirements. Thus, the suggested method constitutes an alternative for the applied method of "trial and error", which usually extends the process of searching for the problem solution. It was verified in this paper on the example of determination of the structural form of a tunnel sprayer which is a typical example of the complex biotechnical system.

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METODYCZNE ASPEKTY PROJEKTOWANIA KONCEPTUALNEGO MASZYNY ROLNICZEJ NA PRZYKŁADZIE OPRYSKIWACZA TUNELOWEGO

Streszczenie. W artykule przedstawiono procedurę postępowania przy wyznaczaniu postaci konstrukcyjnej maszyny rolniczej, uwzględniającą aspekty metodyczne projektowania, związane z podziałem zasadniczej funkcji celu na funkcje składowe, wielowariantowe rozwiązania oraz syntezę postaci konstrukcyjnej (prototyp wirtualny maszyny rolniczej). Proponowany tok postępowania przedstawiony został na przykładzie projektu opryskiwacza tunelowego. Przykład ten dobrze odzwierciedla i uwzględnia specyfikę przedmiotu projektowania, jakim jest maszyna rolnicza o szczególnych wymaganiach technicznych i agrotechnicznych. Zwrócono uwagę na aspekty związane z metodyką wyboru rozwiązań cząstkowych w oparciu o wcześniej ustalone kryteria.

Słowa kluczowe: projektowanie konceptualne, koncepcja, postać konstrukcyjna, wymagania projektowe, karta struktur, opryskiwacz tunelowy