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Design method of technological module for small feed milling plants

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Abstract. The present research is aimed to develop the method of designing technological modules for small feed milling plants. The method consists in efficient placement of the machinery in a frame of a standard module having dimensions of a 20-foot container. The heuristic method of sequentially-single placement of the machinery was applied. The limits and restrictions imposed on placement of machines in the standard module were defined. It was defined that the heuristic method of sequential single placement of the machinery is preferable for production location under condition of limited sizes as it is effective for hardware diagrams with low connectivity. The method is implemented according to the developed incremental algorithm of consecutive single placement of machinery objects in a standard module taking into account their place in a technological chain, overall dimensions, minimum distance between objects, minimal bonding distance to already placed objects and imposed restrictions. The result of algorithm execution represents the diagram of technology machinery in a module on the horizontal plane which can be transformed to a three-dimensional view. The developed method will allow hastening the design process and facilitating decision-making for designers.

1. Introduction

Nowadays, there is a need for creating small feed milling plants in agricultural enterprises in order to provide animal farming with own-produced complete feed.

The need for speedy introduction of new technologies and equipment requires the production of new plants based on innovative principles differing from traditional ones. Modern economy demands small plants to be “real-time enterprises” [1], capable of responding promptly to changing product requirements, the invention of new technologies and equipment for their production [2].

To solve this problem, the concept of small feed milling plant was elaborated on the basis of module structure. The structural unit of the modular feed milling plant is a technological module. Moreover, standard modules are unified on the basis of the integrated structural platform representing a metal frame of dimensions of a one-foot cargo container (6×2.5×2.6 m), where equipment is encased [3, 4] (Figure 1)

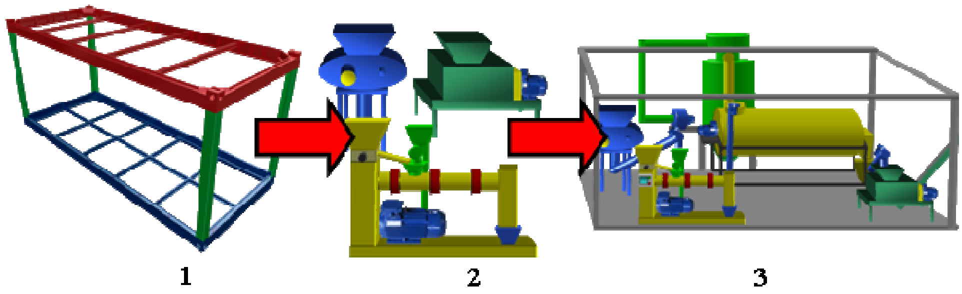

Figure 1. Formation of technological module for a small feed milling plant: 1 - frame with dimensions of 20-foot container; 2 - equipment; 3 - technological module.

A technological module usually consists of one structural platform, but when using a significant number of machines, it can include two or more platforms placed in two levels. The core of the modular enterprise is the main dosing and mixing module for raw materials, which is completed with additional technological modules ensuring the execution of operations on preparing raw materials and final processing of feed. Small plants can include a single module containing all the necessary equipment. The modular structure allows increasing the amount of ways to arrange the enterprise, reducing the time of design and raising the speed and simplicity of installation. One of the important features of the proposed modules is that all equipment is installed inside the frame at the manufacture enterprise, so the customer receives a module ready for use.

When developing a technological module for feed milling plants, the designer faces the problem of the effective placement of equipment in a limited volume of the frame. Moreover, the given set of objects (machines) interconnected to provide communication between them while meeting the set limits should also be placed in a limited volume.

However, the existing methods of designing the arrangement of equipment are aimed to place it inside departments of traditional enterprises having large area, which allows combining it according to a large number of options [6]. The available methods for effective disposing of machines in a small enclosed volume of a module are difficult to applicate and insufficiently develop, when safety requirements and set limits are met [7, 8].

2. Methodology

2.1. Research object
The purpose of the study is to develop a simple and efficient method of designing technological modules for small feed milling plants, which would consist in the optimal arrangement of technological equipment inside a frame of a standard module.

2.2. Research method
The studies were carried out based on the provisions of system analysis and synthesis [9], adapted to be applied in engineering [10, 11], and the modular principle of constructing technical systems [12, 13, 14]. The heuristic method of sequentially-single placement of equipment was used [15].

3. Results

3.1. Method of arranging the equipment in the standard module of limited size
Since the overwhelming majority of machines for small feed milling plants are freely placed in height inside a standard module frame (up to 2.6 m), the problem of their arrangement is reduced to positioning their projections in two-dimensional space (on a horizontal plane). Moreover, during positioning, equipment projections can move inside the module along two axis (X, Y) in rectangular axis and rotate around a Z parallel axis crossing the center of their projection by an angle divisible by

90° (90°, 180°, 270°, 360°).

The following restrictions and limits were applied to place equipment (facilities) in a standard module frame [15, 16]:

– the size of an object should not exceed the size of a module frame;
– objects should be entirely inside the module frame not intersecting with its boundaries (except for silos of raw materials and finished products, as well as aspiration equipment);
– objects should not intersect with each other;
– objects should not intersect with transporting equipment;
– objects should be connected by transporting equipment;
– minimum distance between objects should be at least 0.3 m.

According to current requirements, after placing objects in a module between several machines or between machines and a wall, there should be a technological passage for personnel (at least 0.8 m), which is difficult to ensure with the limited width of a standard module (2.5 m). It is possible to get around this limitation by providing removable (sliding) walls, and when placing the module in a hangar-type room – by absence of walls, thereby ensuring free access for personnel to the equipment from the outside of frame, which allows machines to be placed close to the borders.

It was defined that for the case of such workplace with limited dimensions, as the standard module, the heuristic method of sequentially-single placement of equipment is preferable, since it is effective for machine-hardware circuits with low connectivity [15].

To solve the problem of arranging a standard module, proceeding from its technological and machine-hardware circuits, the flow diagram of raw materials, semi-finished and finished products between the involved machines is worked out, which determines the arrangment order for the objects of equipment. The placement of objects should ensure the consistent movement of material flows during the process, i.e. machines should form a continuous technological chain, which facilitates their arrangment.

3.2. Algorithm of arranging the equipment inside a standard module with limited sizes

The method of sequentially-single placement of equipment is implemented according to the developed step-by-step algorithm, which implies placing a single object (unit of technological equipment) at each step (Figure 2).

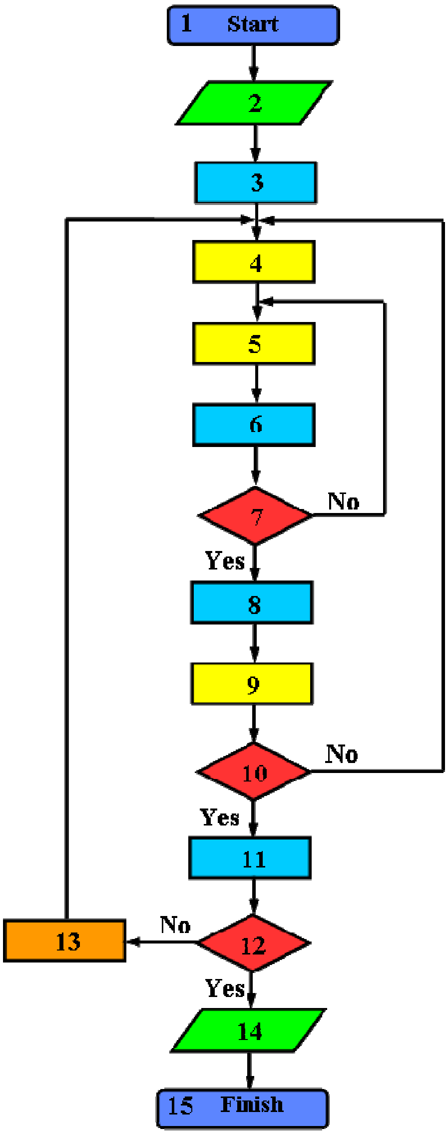

Figure 2. Algorithm of sequentially-single placement of equipment in a standard module of limited size

The algorithm for sequential single placement of equipment in a standard module includes the following steps: 1) starting; 2) inputing initial data (names and number of machines, technological chain, imposed limits); 3) placing a first object; 4) selecting the next object; 5) choosing place for the next object; 6) calculating the bonding distance from the object from (5) to a previous object; 7) checking if all nearby positions are viewed 8) choosing a position with a minimum bonding distanc to a previous object; 9) placing an object in the selected place; 10) checking if all objects are placed 11) placing the last object; 12) does the final arrangment of objects comply with the limits imposed? 13) correcting the array of positions of objects; 14) output data (layout of equipment); 15) the end (transition to preparing construction documentation).

Taking into account the need to ensure the required distance between objects and passages between them, the standard module actually forms a series of previously known positions for equipment and also determines the location of the technological "entrance" and "exit" of the module (they can coincide).

When executing the algorithm, the first object in the technological chain is placed in the first position from the "entrance" of the module (element 3). Then the second object is placed (element 4), for which the positions adjacent to a previous already placed object are used. For an object one sets the position, which when is selected demands a criterion of minimum of bonding distance to already placed objects, taking into account the limits imposed [8].

The bonding distance between objects is determined by the length between geometric centers of projections of these objects on a horizontal plane. In this case, the bonding distance from current to previous object in the processing chain is determined (element 6).

Then the objects (units of equipment) are placed alternately. Thereat the last object in a processing chain is placed taking into account the need to transport processed raw materials or finished products outside the module, so it is located at its "exit" (element 11).

When spatial positioning of objects, it is taken into account that each of them has its own "entrance" for the the raw material and "exit" for the output of the processed product. Therefore, objects should be oriented so that the "exit" of the previous one is aligned with the "entrance" of the next one.

After placing the last object, equipment placement is finally checked for the compliance with limits imposed (element 12). If necessary, the adjustment is made to the arrangement of equipment (element 13). The result is drawn up as a layout of technological equipment in a standard module (element 14).

The implementation of the design algorithm for the placement of equipment in the standard module is illustrated in Figure 3.

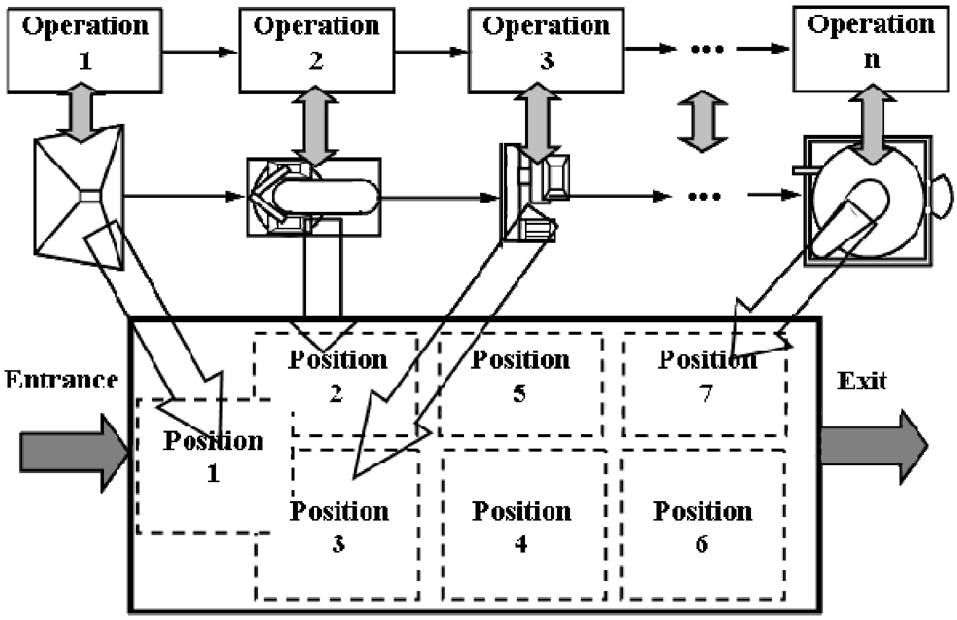

Figure 3. Method of forming a standard technological module.

3.3. *Optimality criterion of the equipment placement*

The layout of equipment in a module developed according to the algorithm should be checked for compliance with the optimality criterion. As a criterion for the optimality of the design solution for the placement of technological equipment, the function of property values of objects (units of equipment) is taken according to the method described in [16]. In case of placing objects in a standard module of limited dimensions, the criterion of the minimum area occupied by equipment is preferable.

Each of the placed objects of technological equipment has properties, particularly geometric dimensions and location relative to X and Y axes in the rectangular coordinate system.

Geometric dimensions of an object are determined by the expressions:

$$a_i = z[s_a, x_i],\ b_i = z[s_b, x_i]. \tag{1}$$

Location of an object relative to X and Y axes of the rectangular coordinate system is determined by the expressions:

$$L_{x,i} = z[s_x, x_i],\ L_{y,i} = z[s_y, x_i]. \tag{2}$$

Taking into account expressions (1) and (2), the criterion for the optimal placement of equipment for the minimum occupied area is:

$$R_s = \min\left(z[s_x, x_i] + \frac{z[s_a, x_i]}{2}\right) \cdot \min\left(z[s_y, x_i] + \frac{z[s_b, x_i]}{2}\right). \tag{3}$$

3.4. Diagram of placing technological equipment in a standard module

The result of the algorithm is the layout of the technological equipment of a standard module on a horizontal plane, which can be converted into a three-dimensional projection via CAD system. After that, the installation diagram is elaborated for transport equipment that connects technological equipment of the module.

Then, when designing, the electrical circuit is developed, as well as a circuit for the automated control system of the module. The location of the entrance and exit for personnel, the presence or absence of side walls and ceiling of the module are assigned. At the end, the final design documentation for a standard technological module is made.

To show the result of using the developed method for designing a standard module, figure 4 presents the diagram of equipment: plane view and general three-dimensional view of the technological module for the production of animal feed with the capacity of 1 t/h.

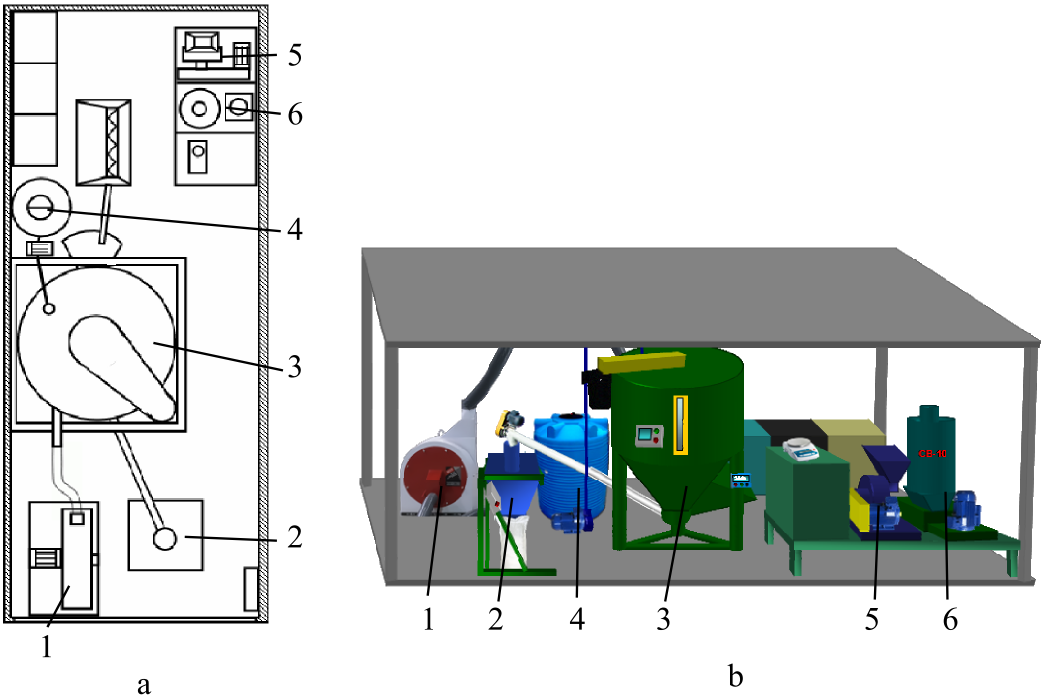

Figure 4. Diagram of equipment in the standard structural module (technological module of grinding and mixing for a small feed milling plant): a - diagram of equipment on a plane; b - general view of the module (three-dimensional projection); 1 – hammermill DM-1; 2 - facility for feedstuff packaging; 3 - vertical mixer USK-1.5; 4 - facility for inputting liquid raw materials; 5 - hammermill MD-0.5; 6 - vertical mixer SV-10.

4. Discussion

The proposed method can significantly facilitate and speed up the design process when arranging equipment in single-compartment premises of limited sizes. This method is quite useful, yet for greater efficiency and operability it should be supplemented with detailed rules for setting the spatial orientation of equipment, particularly the possibility of their rotation about the central axis by certain angle.

5. Conclusion

The elaborated method will significantly speed up the process of designing technological modules for small modular feed milling plants and simplify making decisions for designers when placing equipment in single-compartment premises of limited size. The advantages of this method are low labor intensity, implementation simplicity and taking the limitations into account. This method can also be applied when designing modular plants for the processing of agricultural products.

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