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## **ANALISYS OF VARIABILITY OF THE FAMILY OF PACKAGES AND THE VERSATILE PACKAGING MACHINE DESIGN**

### **Abstract**

*The article provides design and engineering analysis of groups of packages. The relationship between the functional units of packaging machines and related groups designs packages is traced. The method for calculation of the versatility rate of the packaging machine depending on its structure is offered.*

### **1. INTRODUCTION**

The rapid development of science and technology constantly stimulates production. That leads to satiation of the global food market with new products. Product life cycle is getting shorter, and the range of products expands increasingly [1]. As a result, the number of design types of packages increases generating the process of complication of packaging equipment and enhance of its functionality.

In view of considerable diversity of tare and the active development of mechanisms design the practical creating of versatile packaging machines can often be quite a challenge. Application of the described sequence of design is conducted on the example of polyfunctional machines for packing powders in polymeric packages. Such a machine generally consists of a block of functional modules-dispensers for measuring a given dose, a functional module (FM) unit for forming a polymer film package and it's sealing after filling with the metered dose and various auxiliary FM.

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## 2. DESIGN ANALYSIS OF PACKAGES

Evaluation of variability of products is carried out using the mathematical model, the general principles of which is hierarchical decomposition of products on the structural components – elements [2]. Each structural element is characterized by form, design and technological parameters. The elementary transformation of its forming is put in correspondence to each structural element. In turn, each such transformation can be realized with a set of FM. This leads to a complex optimization problem of synthesis of packaging machines with a large number of FM.

A polymeric package can be divided into its component parts: body; top and bottom; top, bottom, longitudinal and angular seams; special items (Fig. 1). Each item can be presented as a set of its variants

$$E_i = \{e_1, e_2, e_3, \dots, e_y\} \quad (1)$$

where:  $e_y$  - any variant of constructive element.

The set E of all structural elements included in the family may be represented as the matrix of  $x \times y$ , x – being the quantity of diverse elements of the package:

$$E = \{E_1 \cup E_2 \cup E_3 \cup \dots \cup E_x\} \quad (2)$$

$$E = \begin{pmatrix} e_{11} & \dots & e_{1y} \\ \dots & & \dots \\ e_{x1} & \dots & e_{xy} \end{pmatrix} \quad (3)$$

Repeatability of the items in a separate product design is characterized with the structural repeatability rate:

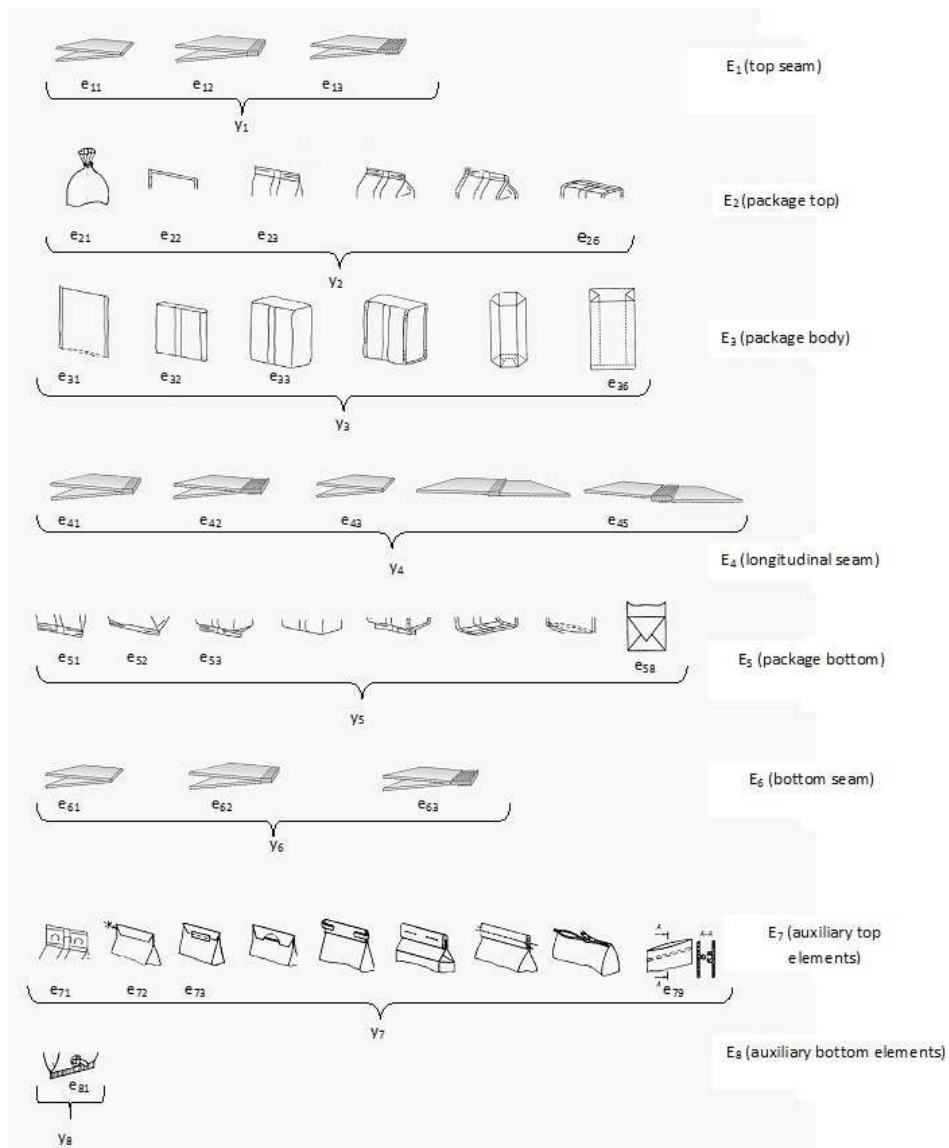
$$U = \frac{\Pi_i}{n_{II}} \quad (4)$$

and a variety of structural elements in the product with respect to all possible designs – the variety rate:

$$V = \frac{\Pi_i}{E} \quad (5)$$

Thus, the generalized coefficient of variability of product family can be defined as the product of averages of the repeatability and variety rates:

$$K_{\text{var}} = \left( \frac{1}{E} \sum \frac{\Pi_i}{n_{\Pi}} \right) \cdot \left( \frac{1}{E} \sum \frac{\Pi_i}{E} \right) = \bar{U} \cdot \bar{V} \quad (6)$$



**Fig. 1.** Family of the elements of package

### 3. CALCULATION OF VERSATILITY FOR TECHNOLOGICAL MACHINES WITH DIFFERENT STRUCTURES

Assume that each FM successively forms the product specific element from a given set of possible sizes.

The total number of products that a packing machine may produce is determined depending on its structure (Fig. 2) and a set of design elements that any FM makes.

For a machine that consists of several sequential working FM the total number of products is defined as the product of the sets of design elements that each of FM can produce:

$$N_{II}^{\phi M} = \prod_{i=1}^x E_i^{\phi M} \quad (7)$$

where:  $E_i^{\phi M}$  – number of options for the design elements of a product that the  $i$ -th FM produces.

Under the serial connection is to be understood a combination of FMs, that can ensure the formation of each element of package at a time, and each subsequent modifying a pretreated product and each finished product must undergo processing by all the FMs.

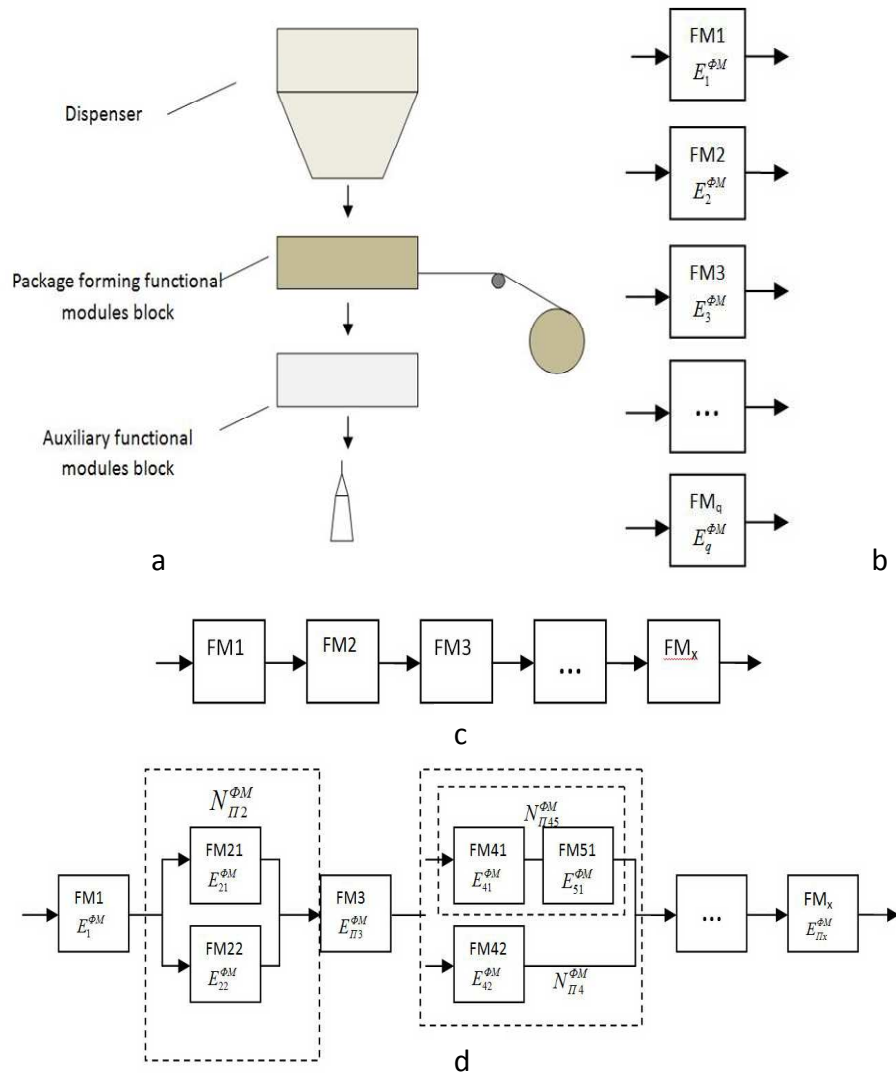
In case when the FM can perform an unlimited number of variants of package elements the versatility factor for it equals to one. But actually this FM does not affect the versatility of the entire machine because those variants of transformations it carries out are be constrained the other FM (e.g. pulling mechanism can move the film on any length, but move step will be determined by the capacity and capabilities of the dispenser and seaming mechanisms). Therefore, the characteristics of such FM can not be taken into account in the calculation of the versatility.

Then the factor of versatility for serial connection the FM is:

$$K_y^{st} = 1 - \frac{1}{E_1^{\phi M} \cdot E_2^{\phi M} \cdot \dots \cdot E_x^{\phi M}} = 1 - \frac{1}{N_{II}^{\phi M}} = 1 - \frac{1}{\frac{1}{1-K_{y1}} \cdot \frac{1}{1-K_{y2}} \cdot \dots \cdot \frac{1}{1-K_{yx}}} = 1 - \prod_{i=1}^x (1-K_{yi}) \quad (8)$$

In real conditions of some of the FM do not provide the necessary elements of product formation [3]. As a consequence, there are impossible combinations

of operations in the process. The versatility losses in each FM will amount.



**Fig. 2. General structure of the packaging machine (a) and the schemes of the parallel (b), serial (c) and mixed (d) connection of FMs**

$$\xi = 1 - \frac{E_i^{\Phi M}}{E_i} \quad (9)$$

For packaging machine, that consists of serial-connected FM's:

$$\Xi^{srl} = \prod_{i=1}^x \left(1 - \frac{E_i}{E_i^{\Phi M}}\right) = \prod_{i=1}^x \xi_i \quad (10)$$

Parallel connection of modules allows the realization of functions at a certain time only one of them. In this case, the number of products that  $q$  parallel-connected FM can produce is determined by the sum of sizes for each of them

$$N^{\Phi M} = \sum_{i=1}^q E_i^{\Phi M} \quad (11)$$

The situations may occur when one or more modules can form the same elements. Then at any time a bunch of parallel-connected modules produces

$$N^{\Phi M} = \bigcup_{i=1}^q E_i^{\Phi M} = \sum_{j=1}^q \Pi_j \quad (12)$$

types of products. Expanding functionality in this case is achieved by unique variants  $\Pi_j$  of structural elements of the product, that each of FM makes. Thus, with the addition of each new module the versatility loss reduces:

$$\Xi^{prl} = 1 - \sum_{i=1}^q \left(1 - \frac{E_i}{E_i^{\Phi M}}\right) = 1 - \sum_{i=1}^q \xi_i \quad (13)$$

For parallel connection FM the coefficient of versatility is determined according to the following dependence:

$$K_v^{prl} = 1 - \frac{1}{\sum_{j=1}^q \Pi_j} = 1 - \frac{1}{1 - \sum_{j=1}^q \left(\frac{1}{1 - K_{vq}}\right)} \quad (14)$$

Mixed FM connection is a combination of serial and parallel. Thus arbitrarily complex machine is reduced to a chain of serial-connected parts. Several FM,

which operate in parallel or sequentially on the same level are considered as one group.

For any machine the number of types and sizes of finished products and versatility coefficient can be calculated by the following dependencies:

$$N^{\Phi M} = \prod_{i=1}^{\alpha} E_i^{\Phi M} \cdot \prod_{i=1}^{\beta} \sum_{j=1}^q \Pi_j \quad (15)$$

$$K_V = 1 - \frac{1}{N^{\Phi M}} = 1 - (K_{V_i}^{srl} \cdot K_{V_i}^{prl}) = 1 - \left( \prod_{i=1}^{\alpha} (1 - K_{V_i}) \cdot \prod_{i=1}^{\beta} \frac{1}{\sum_{j=1}^q \left( \frac{1}{1 - K_{V_q}} \right)} \right) \quad (16)$$

where:  $\alpha$  and  $\beta$  – number of series-connected FM and FM parallel connection, respectively.

The loss of versatility for mixed connection of FM:

$$\Xi = \Xi^{srl} \cdot \prod_{i=1}^{\beta} \Xi^{prl} = \prod_{i=1}^{\alpha} \xi_i \cdot \prod_{i=1}^{\beta} \left( 1 - \sum_{j=1}^q \xi_j \right) \quad (17)$$

Therefore

$$[N] = N^{\Phi M} \cdot \Xi \quad (18)$$

Since always  $\Xi < 1$ , the quantity of types and sizes of packages produced by packaging machine is less than their number in the family:

$$[N] > N^{\Phi M} \quad (19)$$

#### 4. CORRESPONDENCES BETWEEN PRODUCT AND FM DESIGNS

The transition from a family of packages to the structure of packaging machine, occurs due to synthesis of the machine workflow from elementary operations by establishing correspondence between the elements of package design, FM realizing them. This raises some difficulties since the same structural element of package can be formed by various elementary operations, and each of the elementary operations – can be performed by different in design FM. Then

for each design package the set of elementary operations is defined, and each elementary technological operation (ETO) is determined by the set of FM designs for its implementation

$$O_i = \{m_1, m_2, m_3, \dots, m_y\} \quad (20)$$

where:  $m_y$  – any variant is a working body.

For example, the longitudinal seam can be obtained as a result of continuous or discrete heating and compression of film layers with rollers or sponges of various designs. And vice versa - as a result of a basic technological operation depending on the design of FM the family of elements can be identified. In this connection it is necessary to further describe not only the type of structural element, but also a way of its formation. Therefore, during the design process will have two aspects to describe versatile packaging machine:

- Functional description which is the set of simple functions, the implementation of which ensures the formation of structural elements of package (EB) and set of connections between them defining the principles of operation of the packaging machine;
- Structural description which is the set of functional modules that create the layout of packaging machine, variants of their design (KB), and relations between them.

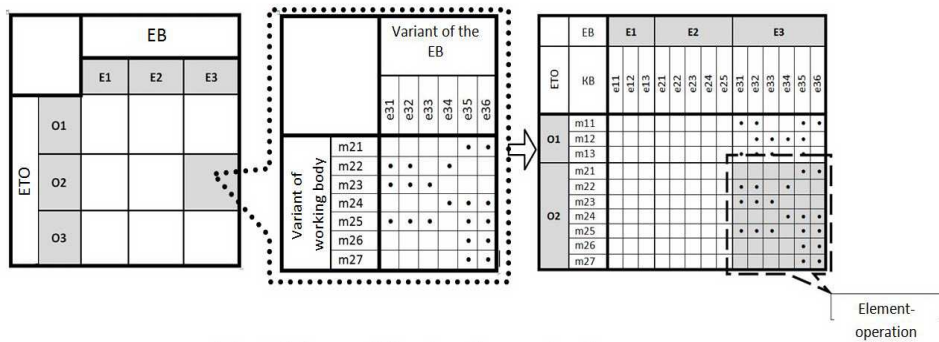


Fig. 3. Scheme of forming the matrix of structures.

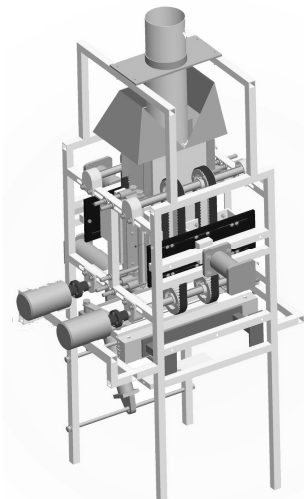
The connections between the components and design FM look like "constructive element - version implementation - process operation - options of the construction". This correspondence is presented with Boolean matrix of structures. Generating of this matrix is based on the set of FM - the fundamental



elements of the design of packaging machine used for formation of the corresponding structural elements of the package and ensuring the implementation of auxiliary functions. The work of a machine is considered as a set of ETO. Thus each ETO is associated with a structural element of the package - thereby defining the element-operation.

After the distinguishing of element-operations, the analysis of need of their implementation for each type of package and creating generalized technological operation of package forming is conducted. The generalized process operation should ensure the formation of structural elements inherent in all types of package in a specified sequence and implementation of support functions. It should also take into account the possibility of overlapping or simultaneous execution of functions. The given summary technological operation covers all possible ETO undertaken during formation package with all structural elements. In fact, it represents the array of designs FM and corresponding elements of the package, i.e. an array of element-operations (Fig. 3).

Transition to the technical description is the most difficult stage. The reason is that the range of elements package meets a wide range of technical functions of package-forming equipment. Given that there is a possibility of providing several functions or simultaneous formation of a family of the package elements decomposition of ETO into multiple simple functions for the relevant technological transformations is carried out. The decomposition is performed until the choice of technical means for each of them becomes apparent, and is provided by the only design of the working body. The result of such a function is the creation or modification of the corresponding version of package constructive element.



**Fig. 4. 3D model of the designed versatile packaging machine**

Spatially the FMs are placed in the order of transitions of the generalized technological operation. Changing the type of package is carried out by turning on or off the mechanisms that form the corresponding components. This completes the goal the versatile packing machine is to achieve - providing the implementation of all functions of package formation.

Basing on the described methodology the versatile packaging module was developed (Fig. 4). It is designed for packing granular products in polymeric packages 15 types with cross-sectional dimension of 90x160mm and seams up to 20mm [4]. The module consists of the following main components and mechanisms:

- mechanism forming a sleeve of film and providing product supply channel;
- pulling mechanisms;
- mechanisms for longitudinal seaming;
- devices formation of lateral folds;
- mechanism for transverse seaming, folding the bottom and cutting-off the finished package;
- mechanism for folding the bottom seam;
- frame.

The drive of mechanisms for longitudinal and transverse seaming and folding bottom is pneumatic while for pulling mechanisms - from the servomotor.

## 5. CONCLUSIONS

One of the promising directions of improving the efficiency of packaging industry is intensification of use of flexible manufacturing cells based on packaging machines. Important in this case is to ensure the versatility of the machines. Increased versatility can be achieved by using multifunctional machine elements as well as by the inclusion of mechanisms that perform new functions into the structure. In any case, the way the combination of elements in the machine should be taken into account.

The method of structural synthesis of versatile packing machines by selecting the order of the combination of technological operations and technical means for their ensuring based on the research of package design is illustrated by the example of the universal unit of functional modules for packaging granular products into plastic bags.

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