Mykhaylo ZAGIRNYAK[1], Iryna SHVEDCHIKOVA[2], Sergiy TKACH[2]

Kremenchuk Mykhailo Ostrohradskiy National University (1), East-Ukrainian Volodymyr Dal National University (2)

Automation design of multi-unit electromechanical structures of magnetic separators

***Abstract**. Practical expediency of application of genetic and geometric modeling methods for automated synthesis of magnetic separator multi-unit (multi-inductor) cylindrical structures is shown. Genetic model of structure formation of cylindrical multi-unit structures of magnetic separators is proposed. «Isomer maker» software enabling spatial arrangements of cylindrical inductors on the basis of the data introduced by the user is developed.*

***Streszczenie.** W artykule pokazano praktyczną celowość aplikacji metody genetycznej I metody modelowania geometrycznego dla automatycznej syntezy separatora magnetycznego wieloinduktorowego o cylindrycznej budowie. Model genetyczny formowania konstrukcji o cylindrycznej wielojednostkowej budowie separatora magnetycznego został zaproponowany. Oprogramowanie ISOMER MAKER umożliwia przestrzenny układ induktorów ma podstawie danych wprowadzonych przez użytkownika. (**Automatyczne projektowanie wielojednostkowych elektromechanicznych struktur w separatorach magnetycznych**).*

Keywords: automated synthesis, magnetic separator, genetic model, replication, symmetry.
Słowa kluczowe: zautomatyzowana synteza, separator magnetyczny, model genetyczny, replikacja, symetria

doi:10.12915/pe.2014.12.74

Introduction

In modern conditions a tendency of progressive increase of structural and functional variety of magnetic separators can be observed [1-3]. This is caused by the necessity to create qualitatively new devices able to provide reliable functioning and required characteristics of the systems in conformity with new operating conditions. In its turn, it stimulates the development of principally new variants of unconventional embodiment magnetic separators.

The problems of search and synthesis of principally new structural varieties of magnetic separators refer to a complex class of indeterminate problems of search design. Results of search problems solution are of a random character and do not guarantee obtaining optimal structural variants. Structural-system approach [4-8] is a new scientific trend, whose methodological instruments enable provision of directivity and completeness of new structures synthesis. Genetic modeling method is one of the instruments of structural-system approach. Application of this method combined with geometric modeling method has already made it possible to obtain a number of engineering solutions to devices for magnetic separation of bulk materials.

Classes of multi-unit (multi-inductor) objects comprise an independent trend in structural evolution of electromechanical systems. Use of several sources (inductors) in magnetic separating devices creates possibilities of acquisition and employment of new properties directed, in particular, to the solution of the following practical problems [1-3]:

- increase of the content of magnetic fraction in the mixture and decrease of its pollution with nonmagnetic particles;
- improvement of the efficiency of the process of metallic inclusions removal;
- expanding the spheres of devices functioning;
- separation of appropriate metallic inclusions according to their size and electric conductivity;
- creation of a magnetic field of the assigned configuration and intensity in the local area of the separator operation zone;
- providing the necessary trajectory of the movement of the separated ferromagnetic particles;
- combination of operations of magnetization and demagnetization of ferromagnetic inclusions in one device, etc.

Examples of multi-unit devices for magnetic separation are shown on Fig.1: electromagnetic pulleys (Fig.1, a), suspended magnetic separators (Fig.1, b). Multi-unit devices also include module-type systems for magnetic separation (Fig.2).

a) b)

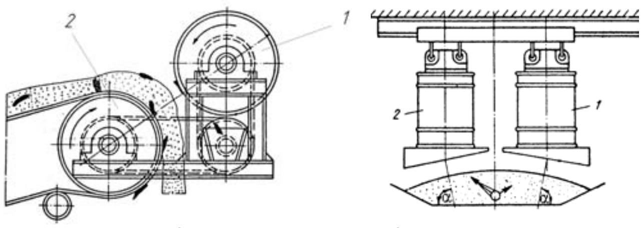

Fig.1. Examples of the multi-unit devices for magnetic separation (1, 2 – electromagnetic systems)

a)

b)

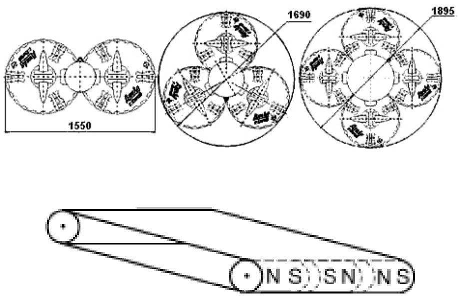

Fig.2. Examples of the module-type systems for magnetic separation

The efficiency of design is substantially determined by the possibilities of its automation. The present paper deals with the discussion of the results of the research of genetic and geometric modeling methods application to automated design of multi-unit (multi-inductor) structures of magnetic separators.

Genetic modelling

As mentioned above, genetic modeling method was developed within the framework of a structural-system approach [4-8]. Genetic models represent processes of development and complication of electromechanical structures with the help of such synthesis genetic operators:

- genetic operator of crossing f_C, modeling spatial cositing of two or more structures ;

- genetic operator of replication f_R (with replication coefficient k_R =2, 3,…), responsible for the change of quantitative composition of the main components of genetic structure;

- genetic operator of mutation f_M, modeling processes connected with the change of geometric dimensions and spatial form of the elements of the electromechanical structure;

- genetic operator of electromagnetic inversion f_{EI}, modeling relative change of spatial orientation of traveling (rotating) electromagnetic fields, electric currents and magnetic fluxes.

From the point of view of genetic concept the process of structures formation within the limits of the type of electromechanical objects is realized through the mechanisms of generation of idealized spatial structures (chromosome sets) at the level of primary field sources. According to the principle of preservation of primary field sources genetic information, signs, peculiar to the structures of genetic level, are preserved in the following generations of structures with a higher level of structural organization [4, 5].

Multi-unit (multi-inductor) systems for magnetic separation, in particular, systems shown on Fig.1, 2 are electromechanical devices created with the use of replication principle [4, 5, 8]. Replication f_R genetic operator responsible for the quantitative compound of structural compositions K, formed from k_R number of homogeneous elements S_0, is the main source of structural variety in genetic modeling

(1) $$f_R(S_0) \rightarrow k_R S_0 \in K.$$

The synthesis of genetic model will be carried out by the example of cylindrical multi-unit structures (genetic codes – CL 0.2y, CL 2.2y) of the family of open-operation-zone magnetic separators. Cylindrical structures (basic types CL 0.2y, CL 2.2y) are dominating structures of magnetic separators class [4, 5]. Generative structure of basic types CL 0.2y and CL 2.2y represents an electromechanical pair created as a result of crossing of a solid-state primary structure (magnetic field inductor) and a secondary discrete structure (ferromagnetic particles) located outside the magnetic field inductor. It also admits the possibility of spatial combination with subsystems of another genetic nature (e.g. nonmagnetic unloading screens) providing rotational movement as well as the possibility of a module construction principle [4-6].

The synthesis of a genetic model is made taking into account the following assumptions:

1. A divergent model of the internal structure of basic type is taken as the basis.
2. At the present stage of the research the maximum value of replication coefficient is assumed equal to k_R =4.

The genetic model graphic interpretation reflecting the multi-level structure of the genome and the structure of the population of multi-unit cylindrical magnetic separators of the basic type (genetic code CL 0.2y or CL 2.2y) is shown in Fig. 3.

The following notations are used in Fig. 3: PFS – primary field source, forming spatial surface of the assigned shape and the law of magnetic field distribution; $S_{0(1)}, S_{0(2)}$ – primary solid state (magnetic field inductor) and secondary discrete (extracted ferromagnetic bodies) structures; S_0 – electromechanical pair or the first generation chromosome set; S_{21I} – synthesized electromechnical structure or the second generation chromosome set presented by replicated (by inductor) generating structures S_{212I} (k_R =2), S_{213I} (k_R =3), S_{214I} (k_R =4); f_C – crossing genetic operator modeling combination of structures with different genetic nature; f_{RI} – replication operator responsible for variation of the quantitative composition of primary solid state structure elements (k_R =2, 3, 4); P_{212I}, P_{213I}, P_{214I} – structural populations of two-, three- and four-inductor systems, respectively.

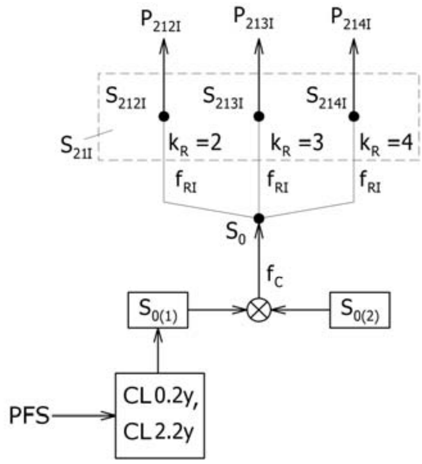

Fig. 3. Genetic model of structure formation of cylindrical multi-unit structures of magnetic separators (basic types CL 0.2y and CL 2.2y)

The first generation chromosome-replicator S_0 (k_R = 1) responsible for inherited characters of magnetic separators one-inductor cylindrical systems is an initial spatial structure in the process of synthesis

(2) $$\left(S_{0(1)} \times S_{0(2)}\right) \rightarrow S_0.$$

Replicated chromosome S_{21I} is responsible for inherited characters of multi-inductor (2≤ k_R ≤4) cylindrical systems

(3) $$S_{21I} = k_R S_0 = \left\langle S_{212I}, S_{213I}, S_{214I} \right\rangle.$$

It is presented by a set of generating replicated structures S_{212I}, S_{213I}, S_{214I}, responsible for inherited characters of two-, three- and four-inductor systems, respectively.

Thus, the structure of the genome of multi-unit structures of magnetic separators (basic types CL 0.2y and CL 2.2y) can be presented by two generations of electromagnetic chromosomes which determine the quantitative composition and genetic information of three structural populations.

Problem statement

Genetically replicated multi-unit structure varieties having common genetic code and consisting of the same number of homogeneous elements S_0, located in the space in specific manner present stereoisomers (stereo isomeric compositions). The property connected with the presence of a great number of variants of spatial arrangement of an equal number of one-type elements S_0 is called space isomerism. Genetic information about stereo isomeric compositions is contained in a replicated chromosome S_{21I} , reflected by a genetic model of structure formation (Fig. 3).

Generation of variants of stereoisomers compositions can be performed by means of sequential application of geometric transformation instrument.

Taking the above mentioned into consideration, the problem of directed synthesis of stereo isomeric compositions of magnetic separators multi-unit structures can be formulated as follows. For the adopted genetic model of structure formation (Fig. 3) and taking into account the limitation imposed on replication coefficient ($k_R \leq 4$), to synthesize a finite set of stereo isomeric compositions of electromechanical multi-unit systems of magnetic separators with cylindrical sources (inductors) of magnetic field.

Multi-unit electromechanical structures automated synthesis using method of geometric modelling

Finite sets of stereo isomeric compositions synthesized on the basis of replicated structures S_{212I} , S_{213I} , S_{214I} can be presented in the form

(4) $$f(S_{212I}) \rightarrow (S_{212I1}, S_{212I2}, ..., S_{212Ik}),$$

(5) $$f(S_{213I}) \rightarrow (S_{213I1}, S_{213I2}, ..., S_{213Ip}),$$

(6) $$f(S_{214I}) \rightarrow (S_{214I1}, S_{214I2}, ..., S_{214Iq}),$$

where f – geometric transformation operator based on the use of symmetry rules; k, p, q – maximum number of practically obtained stereoisomers at k_R =2, 3 and 4, respectively.

Replicated structures S_{212I} , S_{213I} , S_{214I} present a foreseen component of synthesis result and form the basis for solution of problems of directed synthesis of patentable engineering solutions during the process of magnetic separator design. In the genetic model of structure formation (Fig. 3) replicated structures S_{212I} , S_{213I} , S_{214I} are reflected by corresponding branch nodes with designation of structural codes of isomeric compositions and populations generated by them (Fig.4).

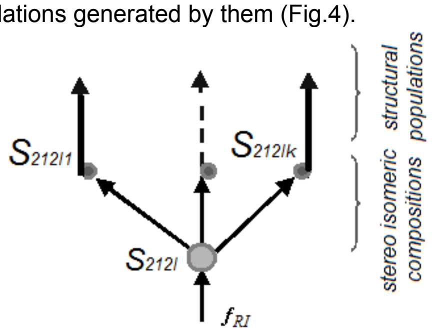

Fig. 4. Graphic representation of a branch node (using replicated structures S_{212I} as an example) in a genetic model of structure formation

Software «*Isomer maker*» was created by the authors for automated synthesis of stereo compositions of multi-unit electromechanical systems with cylindrical sources (inductors) of magnetic field [9]. Synthesis of multi-unit systems for magnetic separation is the main sphere of the software application. The software provides the possibility to form spatial arrangements of cylindrical inductors on the basis of data introduced by the user. The operation principle of«*Isomer maker»* is based on the use of symmetry rules. Conditional representation of magnetic field source is performed in the form of a section of a straight line – the axis of the cylinder. The software has a user's intuitive interface and represents a synthesized spatial composition in three projections (*XY*, *YZ*, *XZ*), as well as in *3D* (rectangular dimetry), as it is shown in Fig. 5 for the case when k_R = 4. The software gives a sequence number to the synthesized composition on the basis of the data of the spatial location of the field sources. Besides, there is a possibility of presentation of the whole formation process in an encoded form. The coordinates of the ends of the built sections-axes and their calculated lengths are also accessible for the user to review (Fig. 5).

Software «*Isomer maker*» was used to synthesize 2793 stereo compositions (isomers) of cylindrical multi-unit systems for magnetic separation, including 49 – with two (k_R = 2), 343 – with three (k_R = 3) and 2401 – with four (k_R = 4) magnetic field inductors, respectively. Presence of known structural variants of magnetic separators among the synthesized compositions proves the validity of the performed procedure.

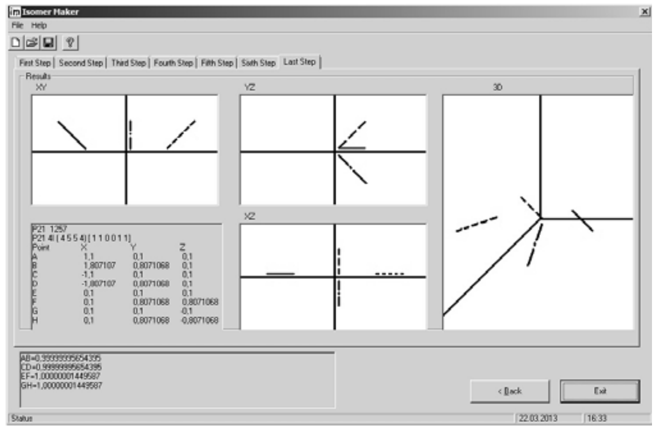

Fig. 5. Representation of the results of «*Isomer maker*» software performance (k_R= 4)

Thus, automation of stereo compositions synthesis makes it possible to significantly reduce the time spent on design of multi-unit electromechanical devices. The results of the synthesis were made the basis of creation of a number of new patentable engineering solutions to devices for magnetic separation.

New engineering solutions

Using the above stated approach and software «*Isomer maker*», the authors proposed several patentable devices for magnetic separation. Some of them are described below.

A device for magnetic separation of bulk materials [10], shown in Fig. 6, includes cylindrical electromagnetic systems 1 and 2, mounted with the possibility of rotation on their own axes at an angle of α to the base of conveyer 3. Variation of mounting angle α of electromagnetic systems is made by means of brackets 4 and 5.

The proposed device (Fig. 6) operates in the following way. Electric current is supplied to electromagnetic systems 1 and 2. Ferromagnetic particles transported together with bulk material by conveyer 3 are attracted to the working surfaces of electromagnetic systems 1 and 2 under the action of magnetic forces. Due to the possibility of rotation of electromagnetic systems on their axes the ferromagnetic particles are carried by them into the unloading zone. Bulk material, purified from ferromagnetic inclusions, is directed to a special receiver by means of conveyer 3.

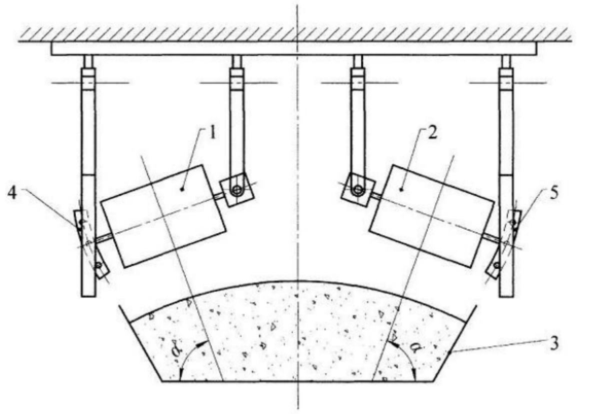

Fig.6. Device for magnetic separation of bulk materials [10]

Angle α (Fig.6), at which electromagnetic systems 1 and 2 are mounted on the basis of the conveyer, may vary taking a fixed value from the range of 60-90° depending on the angle of the natural slope of the material. Besides, using brackets 4 and 5, it is possible to regulate the distance between the working surfaces of electromagnetic systems and the surface of the transported material.

In the bulk materials separation device, schematically shown in Fig. 7 [11], electromagnetic systems 1 and 2 are also made in the form of cylinders with the possibility of rotation on their own axes and brackets 3 and 4 allow variation of the electromagnetic systems mounting angle α to the conveyer basis. Unlike the device shown in Fig. 5, electromagnetic systems 1 and 2 in the considered device (Fig. 7) are located at a certain distance from one another in such a way that each of them crosses the symmetry axis of conveyer 5.

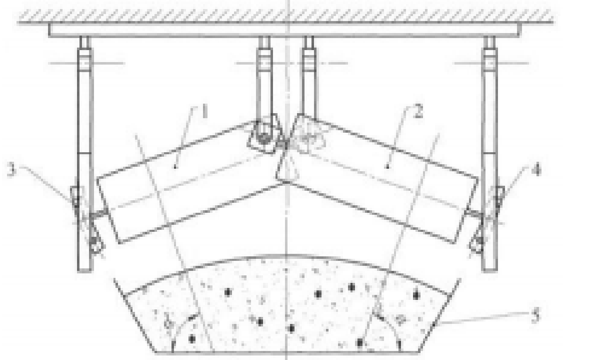

Fig. 7. Device for magnetic separation of bulk materials [11]

Ferromagnetic particles transported together with the bulk material by conveyer 5 (Fig. 7), under the action of magnetic forces, are attracted first to the working surface of electromagnetic system 1 and then to the working surface of electromagnetic system 2 located at a certain distance from electromagnetic system 1. Due to the possibility of rotation of electromagnetic systems on their axes the ferromagnetic inclusions are carried by them into the unloading zone. Mounting of electromagnetic systems 1 and 2 at a certain distance from one another promotes the improvement of the quality of removal of metallic inclusions in the part of the working area where the biggest layer of bulk material is situated and also reduces the interference of the electric systems.

Thus, rational variants forming the basis for development of new patentable engineering solutions were chosen from a multitude of isomeric compositions of multi-element cylindrical structures synthesized with the use of software «*Isomer maker*».

Conclusions

It has been shown that combined use of genetic and geometric modeling methods provides good opportunities for the synthesis of new structural variants of multi-unit electromechanical devices when the designing process is automated. The possibility of directed generation of new structural variants of multi-unit devices whose novelty has been confirmed by patents obtained by the authors proves the adequacy of the synthesis procedure.

REFERENCES

[1] Zagirnyak M., Magnetic Separators, *Proceedings of the seventeenth International Electrotechnical and Computer science Conference ERK*, Portorož, (2008), 7-8

[2] Svoboda J., Magnetic Methods for the Treatment of minerals, *Elsiver*, (1987), 692

[3] Unkelbach K. Magnetic separators mode of operation and applicability for the separation of materials, *Köln, KHD Humboldt Wedag AG*, (1990), 87

[4] Shinkarenko V., Zagirnyak M., Shvedchikova I., Structural-systematic Approach to Magnetic Separators Design, *Studies in Computational Intelligence. Computational Method for the Innovative Design of Electrical Devices, Springer,* 327(2011), 201-217

[5] Zagirnyak M., Shvedchikova I., Miljavec D., Forming a genetic record of cylindrical magnetic separator structures, *Przegląd Elektrotechniczny (Electrical Review)*, (2011), No. 3, 220-223

[6] Shinkarenko V., Gaidaienko Yu., Ahmad N. Al-Husban, Decoding and Functional Analysis of Genetic Programs of Hybrid Electromechanical Structures, *Modern Applied Science*, (2014), Vol. 8, No. 2, 36-48

[7] Shinkarenko V., Zagirnyak M., Shvedchikova I., Methods for using intertype homology for synthesizing new structural versions of magnetic separators. *Russian Electrical Engineering*, (2010), No. 81 (9), 504-508

[8] Zagirnyak M., Shvedchikova I., Genetic synthesis of new magnetic separators structures, *Computational Problems of Electrical Engineering* (2011), Vol.1, No. 1, 125-128

[9] Veligura A., Shvedchikova I., Tkach S., Software „Isomer maker", Copyright registration certificate No. *49759 (Ukraine)*, (2013)

[10] Shvedchikova I., Tkach S., Device for magnetic separation of bulk materials, *Patent 69845 (Ukraine)*, (2012)

[11] Shvedchikova I., Tkach S., Device for magnetic separation of bulk materials, *Patent 78665 (Ukraine)*, (2013)

***Authors**: prof. D. S. Mykhaylo Zagirnyak, Kremenchuk Mykhailo Ostrohradskiy National University, vul. Pershotravneva, 20, 39600 Kremenchuk, Ukraine, E-mail: mzagirn@kdu.edu.ua; prof. D. S. Iryna Shvedchikova, East-Ukrainian Volodymyr Dal National University, bl. Molodezny, 20-a, 91034 Lugansk, Ukraine, E-mail: ishved@i.ua; mgr eng. Sergiy Tkach, East-Ukrainian Volodymyr Dal National University, bl. Molodezny, 20-a, 91034 Lugansk, Ukraine, E-mail: akjeres@i.ua*