

# DEVELOPMENT OF SYSTEMATICS RANKED STRUCTURE OF ENVIRONMENTAL PROTECTING EQUIPMENT FOR CLEANING OF GAS EMISSIONS, WASTEWATER AND SOLID WASTE

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*Розглянуто підходи до класифікації методів та технічних засобів очистки газових викидів, стічних вод та переробки твердих відходів. Обґрунтовано вибір об'єкту дослідження – функціонального класу природоохоронного обладнання для магнітної очистки. Розроблено концепцію систематики для обраного функціонального класу. Визначено рангову структуру систематики природоохоронного обладнання у відповідності до прийнятої цільової функції*

*Ключові слова: рангова структура систематики, природоохоронне обладнання, магнітний сепаратор, генетичний код*

*Рассмотрены подходы к классификации методов и технических средств очистки газовых выбросов, сточных вод и переработки твердых отходов. Обоснован выбор объекта исследования – функционального класса природоохранного оборудования для магнитной очистки. Разработана концепция систематики для выбранного функционального класса. Определена ранговая структура систематики природоохранного оборудования в соответствии с принятой целевой функцией*

*Ключевые слова: ранговая структура систематики, природоохранное оборудование, магнитный сепаратор, генетический код*

## 1. Introduction

A continuous process of environmental deterioration in Ukraine negatively affects the quality of life and poses a threat to national security in the environmental, economic and social areas. Therefore, it is necessary to restore the natural resources by making production more environmentally-friendly: improving techniques and technologies through application of technical measures and increasing the efficiency of labour in the environmental area. All this determines the relevance of training of highly qualified environmental experts (EE) to be able to solve complex environmental problems. Specialist in environmental protection should be clear about the methods and technical means of purification of air, water and solid waste.

Due to the rapid growth of scientific and technical information, diversification and complication of environment protecting equipment (EPE), it is difficult for EE to choose the technical equipment taking into account the environmental parameters of its exploitation. Hence, arises the topical problem of creation of systematics for EPE that will enable its appropriate choice by experts for its later exploitation.

## 2. Literature review and problem statement

From the prospective of a systematic approach all technological processes are divided into three categories: not

closed (open), closed and isolated. Not closed include the absolute majority of technological processes when production of useful products is accompanied by unavoidable emissions of energy (thermal emitting, vibrations) and substance waste (solid, liquid and gaseous emissions). With the purpose of minimization of the negative impact of substance waste on the environment, purification operations are carried out with the help of EPE, the variety of which is sorted in the compliance with the multiple classifications. There are also EPE for purification of gas emissions, wastewater and processing of solid waste. Most classifications use methods and technical means of purification as classification criteria. In turn, the division of technical means is made on the basis of the principle of performance and design features. The work of [1] studies the filtration equipment used for purification of air and gases. Profound review of methods of gases purification from solid particles and other admixtures produced during gasification of coal or biomass is given in [2]. The analysis of efficiency of equipment for purification of gas emissions from finely dispersed suspended particles is made in [3]. Classification of methods of industrial water purification (lightening) is considered in [4, 5], where they were grouped into: mechanical, physical, chemical, biological, and complex. Lattice, horizontal tanks, oil traps, pressure and non-pressure hydraulic cyclones, micro filters that have large structural diversity are used for purification of wastewater [5].

For solid industrial waste there are the most common methods of preparation and processing, such as grinding, enlargement of particle size, classification and sorting, enrichment, heat purification, leaching, and dehydration. Enrichment is carried out by releasing of one or more components of the total mass of waste. The most common are gravity, flotation, magnetic and electric enrichment methods. The study of [6] reviews the methods of separation and recycling of metals from waste of the electronics industry. Electromagnetic iron separators (drum-type magnetic separators, suspended self-discharging separators), designed to remove iron and other ferromagnetic objects from loosened non-magnetic materials are widely used in the processing of solid waste [7].

The analysis of the literature [1–7] showed that the existing classification of EPE for the purification of gas emissions, wastewater and processing of solid waste cannot serve as a universal basis for the ordering of the growing diversity of EPE. This complicates the choice of necessary methods and equipment depending on the specific conditions of their exploitation. Consequently, there is an unresolved problem to create common for all kinds of EPE classification with the status of taxonomy to organize objects regardless of their complexity and functionality.

**3. The purpose and objectives of the study**

The aim of the paper is to build the ranked structure of the basic taxa of EPE systematics for purification of gas emissions, wastewater and processing of solid waste, which is based on the use of natural classification characteristics and takes into account the environment, where the purification is carried out.

To achieve this goal the following tasks are set:

- determination of the research object (functional class of EPE);
- development of the concept of systematics for the investigated functional class of EPE;
- determination of the ranked structure of systematics of EPE in accordance with the accepted target function.

**4. Determination of the object of study for the formation of the ranked structure of systematics of EPE**

Solving the task of determining the object of the study was conducted by compiling information on existing methods and technical means of purification of gas emissions, wastewater and processing of solid waste. The results of this synthesis are shown in the form of schemes presented in Fig. 1–3.

As shown in Fig. 1, methods of purification of industrial gases from suspended impurities are based on the use of electric, adsorption, magnetic, chemical and combined methods, each of which involves the use of a certain kind of EPE.

All existing wastewater purification methods can be combined into groups as shown in Fig. 2. The sequence of use of various methods depends

on the contamination level and on the pollutants' composition and quality.

To enrich the industrial solid waste, the most common methods are gravity, flotation, magnetic and electrical (Fig. 3).

The results of the generalization of classification of EPE for purification of gas emissions, wastewater and processing of solid waste suggest that everywhere the physical methods of purification are present with the use of technical devices – separators, whose operation is based on the use of physical fields of different nature and some physical properties of materials (magnetization, density, conductivity, dielectric constant, the ability to adsorb etc.). In practice, the most widely used are magnetic separators in which the separation of mixtures of particles is under the influence of the magnetic (electromagnetic) field created in the workspace of devices (Fig. 1–3 highlight the corresponding circuit elements). The device uses the differences in the magnetic properties of materials. Magnetic purification methods have high selection capability and a high level of purification [8–12].

Classification of magnetic separators depending on cleaning medium is generalized in Fig. 4.

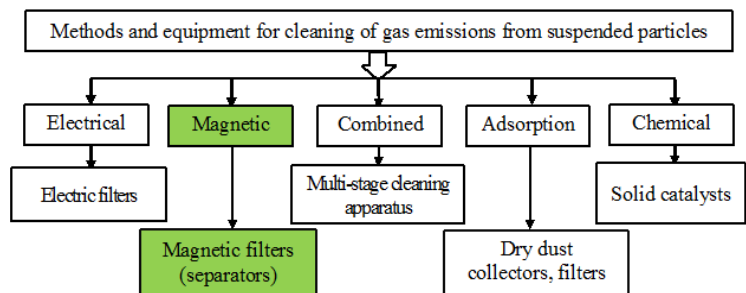


Fig. 1. Classification of methods and equipment for cleaning of gas emissions from suspended particles

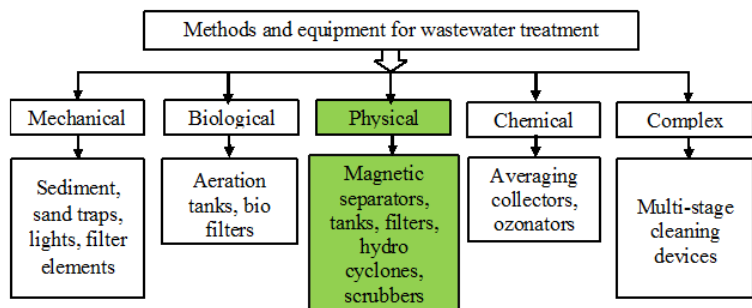


Fig. 2. Classification of methods and equipment for wastewater treatment

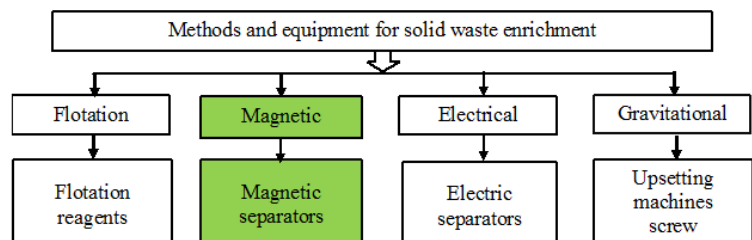


Fig. 3. Classification of methods and equipment for solid waste enrichment

In view of the above, the subject of further studies is a functional class of magnetic separators as a compilation of technically implemented, described in the information

sources, and potentially possible electromechanical devices. Structural representatives of the functional class of magnetic separators are united by the essential common features and by the capability to realize the function of magnetic purification of gas emissions, wastewater and solid waste.

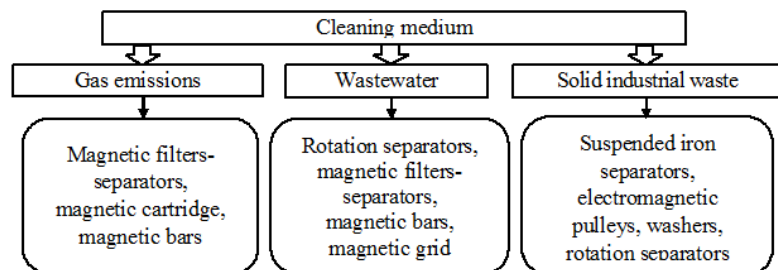


Fig. 4. Classification of magnetic separators depending on cleaning medium

A variety of applications of magnetic separators causes a wide variety of their designs. Choice of appropriate design of devices for magnetic cleaning to ensure environmentally safe conditions of technical processes flow is a difficult task. It can be resolved only by organizing and structuring information on existing classes of magnetic separators, in other words building up their systematics.

### 5. Development of the concept of systematics of EPE for magnetic cleaning

To build a systematics of the ranked structure of the selected functional class the concept is offered. The concept (lat. *conceptio* – understanding, system) is a system of views on the processes in nature and society, a certain way of interpretation of any phenomena, leading point of view that highlights events [13]. Any concept has the structure and components (conceptual apparatus, idea, purpose, concept objectives, implementation mechanism, etc.). The demands to developing of the concept are: theoretical (completeness and consistency) and applied (uniformity, feasibility and potential). Taking the said above into consideration, the concept of the systematics of EPE contains the purpose, theory and methods used to achieve it, the conceptual apparatus, principles and results (Fig. 5).

The main aim of the concept is to develop the ranked structure of EPE’s systematics on the example of the functional class of devices for magnetic cleaning for ordering of the structural diversity of existing and potential class objects.

The methodological basis of the concept consists of theories and scientific approaches, according to which the object is viewed from different positions, depending on the general belief system in the specific area of knowledge and with a focus on certain features. Scientific and methodological basis for formation of the systematics of EPE for magnetic cleaning is the structural and systemic approach (SSA), based on

the theory of evolution of electromechanical systems, which covers two of the latest scientific areas related to the structural and genetic electromechanics [14–16].

The structural and systemic approach emerged after the discovery of the periodic system (genetic classification) of elementary electromagnetic structures or primary sources of electromagnetic fields (spatial surfaces with a given type and distribution law of electromagnetic field) and decryption of universal genetic codes of electromagnetic structures [14]. Building of systematics is guided by a single methodological approach, both in relation to the objectives of determining the classification (identification of the genetic codes) and the division of electromechanical devices into systematic units (taxa).

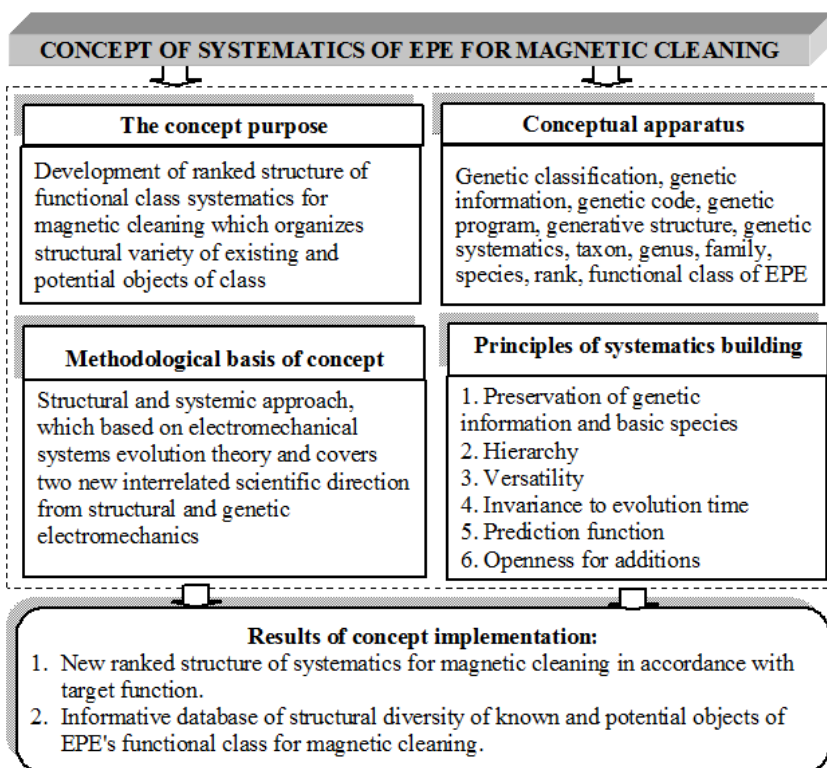


Fig. 5. Concept of EPE’s systematics for magnetic cleaning

The methodology of the structural and systemic approach makes use of the creation of the concept of specific concept apparatus that includes the following basic definitions: genetic classification (GC), genetic information, genetic code, genetic program, generative structure, genetic systematics, taxon, genus, family, species, rank, functional class of EPE. Taking the scientific papers [14, 16] into account the following terminological definitions of these concepts are proposed:

– genetic classification – a kind of a natural classification of periodical type, structural elements of which are endowed with genetic information; a classification of prognostic type, which organizes the genetic information (genetic codes) of the primary elements; an arbitrary classification that organizes objects or their properties on the basis of genetic information;

– genetic information – the genetic information of an arbitrary object, represented by the universal genetic code;

– the genetic code – the universal form of presenting genetic information of an arbitrary element in the periodic composition, elements of which for real electromechanical facilities are based on the analysis of its essential features, including: spatial geometry of the active surface of the primary part of an object (CL – cylindrical, CN – conical, FL – flat, TF – toroidal flat, TC – toroidal cylindrical, SP – spherical); kind of spatial movement of the movable part of an object (rotational, translational, screwing); the physical condition of the secondary medium (solid, discrete ferromagnetic particles, hot metal, etc.); the number of primary and secondary parts; the presence (or absence) of possibility for combination with mechanical, electronic and other components;

– genetic program – a necessary component of the genetically organized system that determines the genetically allowable structural diversity and genetic variation limits of structures;

– generative structure – primary structure, with the advent of which evolution of functional classes of EPE or of certain categories begins;

– genetic taxonomy – the genetically organized classification of objects of certain physical or abstract nature; the structure of its main taxa is determined by the periodic structure of the genetic classification;

– taxon (from Greek – *order, placement*) – genetically defined group of discrete classes of objects united by common characteristics and properties that are within the concept of taxonomic categories;

– genus – systematic unit prior to kind that combines geometrically related species of electromechanical systems. Species diversity of arbitrary genus is determined by cell (chromosomal) set of the corresponding small period of GC;

– family – basic taxonomic unit prior to genus in the ranked structure of the genetic taxonomy. Taxonomic structure of arbitrary family consists of genera and species;

– species – one of the main structural units in the hierarchy of genetically organized systems (taxonomic category);

– rank – the level of systematic unit (taxa) in the taxonomic hierarchy of taxonomy;

– functional class of EPE – genetically determined class of electromechanical objects of EPE, limits of existence and taxonomic structure of which are determined by its objective function according to the environment of their application. The scope and structure of each functional class are clearly defined on the basic level of genetic classification.

One of the cornerstones of the concept building is the issue on the definition of fundamental principles on which the taxonomy of EPE should be based. Principle (from Lat. *principium* – beginning, foundation) is a specific rule, formulated on the basis of knowledge of the laws or regularities to do something in a specified way; theoretical generalization that includes the assumptions and averaging, which reflect certain trends of the system development [14]. Principles, unlike laws, objectively do not exist. They are created in the process of knowledge systematization and act as certain tenets that can be considered as a form of implementation of the law.

Based on the principles of genetic taxonomy presented in [14], the main principles of building of EPE's taxonomy include:

1. The principle of conservation of genetic information and of basic types. Systematics organizes a basic set of elements and synthesized descendants' structures by the common origin that is by the relevant natural (geometrical, electromagnetic and topological) characteristics. Genetic

classification serves as a genetic (natural) basis for the definition of basic taxonomic units.

2. Hierarchy. Reflection of the principle of hierarchy is a ranked systematic structure. It is a hierarchical sequence of taxa ("Species"→"Genus"→"Family"), which clearly define the boundaries, system properties and genetic relationships between taxonomic units.

3. Versatility. Ranked sequence of basic taxonomic units is universal for any functional classes of EPE, whose operation principle is based on electromechanical energy conversion, providing methodological unity and invariance of the systematics structure.

4. Invariance with regard to evolution time. Systematics structure remains unchanged both regarding the existing and in relation to the potential classes of electromechanical objects of EPE.

5. Prediction function. The structure and methodology of taxonomy provides the ability to define and manage structural classes of objects, which are still missing at an exact time of evolution.

6. Openness. Taxonomy structure allows the addition of new taxonomic and auxiliary units and is open in relation to the potential variety of structural system classes.

That is why, given all of the above, it can be argued that the designed concept will provide conditions for building a ranked structure of EPE taxonomy in accordance with the set target function, which covers the essential features of structural classes of devices for magnetic purification.

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## 6. The ranked structure of environment protecting equipment systematics

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In a hierarchically organized structure of genetic taxonomy the major taxonomic category is the Species, that is why it is necessary to determine the full species composition of the investigated class of devices for magnetic purification. In accordance with the principle of conservation of genetic information and basic types, species diversity of EPE for magnetic purification is determined by the concept of the existence of  $Q_{EPEMC}$  field of generating (primary) structures [14]. To find the  $Q_{EPEMC}$  field it is necessary to determine the target integrated search function F:

$$F=(F_1, F_2, \dots, F_n), \quad (1)$$

where  $F_1, F_2, \dots, F_n$  – local search functions, summarizing the essential features of possible structural classes of magnetic purification devices ( $n$  – number of structural classes).

The analysis of magnetic separators, depending on the environment where the purification (Fig. 4) is carried out. It is shown that there are three most commonly used structural classes of devices [7–12]:

1. Devices with open magnetic systems, in which the working area with the magnetic field is external in relation to the poles of the system. These devices include suspended self-discharging separators, electromagnetic pulleys, electromagnetic washers (purification of solid industrial waste); drum separators (purification of industrial solid waste and wastewater).

2. Filter separators (high gradient) belong to the class of combined technical systems and structurally unite the electromagnetic system (the source of the magnetic field) and the working body (filter matrix filled with ferromagnetic ob-

jects of a certain geometrical shape) are used for purification of wastewater, industrial fluids and process gases.

3. Magnetic devices for piping systems which have no source of magnetic field, and working elements (rods, bars) of which are made on the basis of magnetic solids and are used for the purification of technical fluids and process gases.

In further research, we will confine to the study of these three structural classes of devices, summarizing their essential features by the following targeted search functions (TSF):  $F_1$  – TSF of  $Q_1$  area of generated structures of the EPE with the open magnetic systems (first structural class);  $F_2$  – TSF of  $Q_2$  area of generating structures of filters-separators (second structural class);  $F_3$  – TSF of  $Q_3$  area of generating structures of magnetic devices for pipe systems (third structural class).

Consequently, integrated F search function of  $Q_{EPEMC} = (Q_1, Q_2, Q_3)$  existence area of generated structures of EPE for magnetic purification will be as follows:

$$F = (F_1, F_2, F_3). \tag{2}$$

Taking into account the results of systematic research, which are reflected in the works [14–17], we will consider the features of the EPE systematics on the example of the magnetic separating devices with open magnetic systems. Delimitation of existence of  $Q_1$  area of generated structures of devices of this class is made in accordance with the objective function  $F_1$  of the type:

$$F_1 = (p_1, p_2, p_3, p_4), \tag{3}$$

where  $p_1$  – the presence of primary solid structure (the source of the magnetic field);  $p_2$  – the presence of discrete secondary structure (ferromagnetic bodies that are eliminated);  $p_3$  – the presence of required space of working area that is long and high enough;  $p_4$  – the possibility of placement of non-magnetic handling screen that provides rotational or translational motion in the space between the primary and secondary structures [15].

To determine the correct  $Q_1$  area the following assumptions and limitations are accepted:

- search is carried out within the first great period GC ( $S_{00}$ );
- spatial movement of the magnetic system (or non-magnetic handling screen) is rotational ( $Q_{1rot}$  existence area) or progressive ( $Q_{1p}$  existence area);
- only the Species of the basic level are used for calculation (genetically modified and complex structures – multiple inductor, combined, etc. are not considered);
- at this stage of studies the “twins” Species are not examined.

Considering the given set of constraints,  $Q_1$  existence area of species diversity of the class that meets a given  $F_1$ , is:

$$Q_1 = (Q_{1rot}, Q_{1p}) \subset S_{00}. \tag{4}$$

Existence areas of generated structures of rotational  $Q_{1rot}$  and translational  $Q_{1p}$  motion are defined, respectively, by the following expressions [15]:

$$\begin{aligned} Q_{1rot} = & (TF\ 0.0y, CL\ 0.2y, CN\ 0.2y, TF\ 0.2y, SP\ 0.2y, \\ & CL\ 2.2y, CN\ 2.2y, TF\ 2.2y, SP\ 2.2y, \\ & SP\ 2.2x, TC\ 0.2y, TC\ 2.2y), \end{aligned} \tag{5}$$

$$\begin{aligned} Q_{1p} = & (TF\ 0.0x, FL\ 0.2y, CL\ 2.0x, CN\ 2.0x, FL\ 2.0x, \\ & TF\ 2.0x, CL\ 2.2x, CN\ 2.2x, \\ & FL\ 2.2x, FL\ 2.2y, TF\ 2.2x), \end{aligned} \tag{6}$$

where TF 0.0y... TF 2.2x – genetic codes of the corresponding primary structures (field sources) of basic structures.

Expressions (5), (6) represent the genetic program of the researched class of EPE for magnetic purification. In accordance with the principle of conservation of genetic information each of generated primary structure in these functions is associated with a certain structure of EPE Species (really – informational or implicit). Given the identity of the genetic information in such structures as FL 2.2x=FL 2.2y and SP 2.2x=SP 2.2y, the total number of generated structures of the investigated class is 21. The structural diversity of EPE for magnetic purification is presented in all 6 geometric classes.

The procedure of the genetic code identification is carried out on the example of real electromechanical object – electromagnetic pulley (Fig. 6), which is used for industrial solid waste purification [15]:

- the spatial geometry of the field source – cylindrical (CL);
- windings type – in the direction of rotation, the winding of the field source has no edges – symmetry (0);
- in the transverse direction, the winding has a frontal part (edge) – asymmetry (2);
- direction of spatial movement of moving parts – rotational, transverse spatial orientation (y).

Identification of the genetic code of real electromechanical object (Fig. 6) and genetic analysis of its structure allows determining which basic Species the electromagnetic pulley belongs to: cylindrical, longitudinally symmetrical, y-oriented structure (CL 0.2y). The genetic code also indicates the identity of the object to prior to Species taxa. Thus, electromagnetic pulley (Fig. 6) as representative of the CL 0.2y Species can be attributed to the kind of cylindrical, to the subfamily of rotary motion devices and family of EPE for magnetic purification with open magnetic systems.

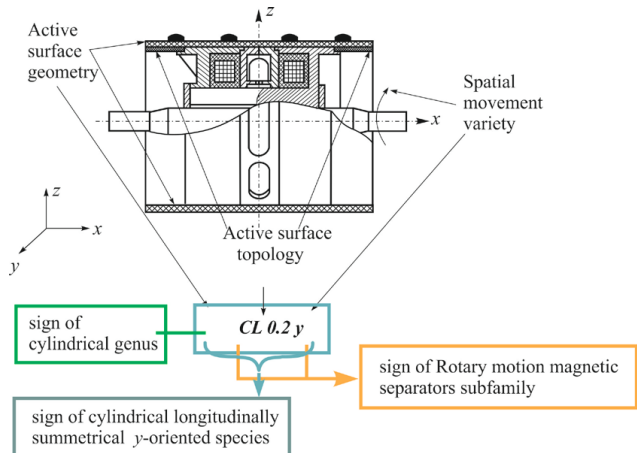


Fig. 6. Connection of genetic code with magnetic separator essential features and taxonomic categories (on example of electromagnetic pulley)

Availability of system information on the number of species and genetic structure of Species allows to determine the ranked structure of the main taxonomic units of the class in which “Species” plays the function of the main systematic

category for taxa of prior to species levels: “Species”→“Genus”→“Subfamily”→“Family”. Structural diversity of species is determined by a combination of genetically related species, which are united by common spatial geometry of the primary field source [17]. Classes of magnetic purification EPE of rotational and translational motion have the status of subfamilies, as they unite the corresponding generic taxa by the nature of spatial movement. Structural class of EPE for magnetic purification with the open magnetic system corresponds to the status of the family.

Thus, the ranked structure of the main taxonomic units of the functional class of EPE for magnetic purification has the form shown in Fig. 7.

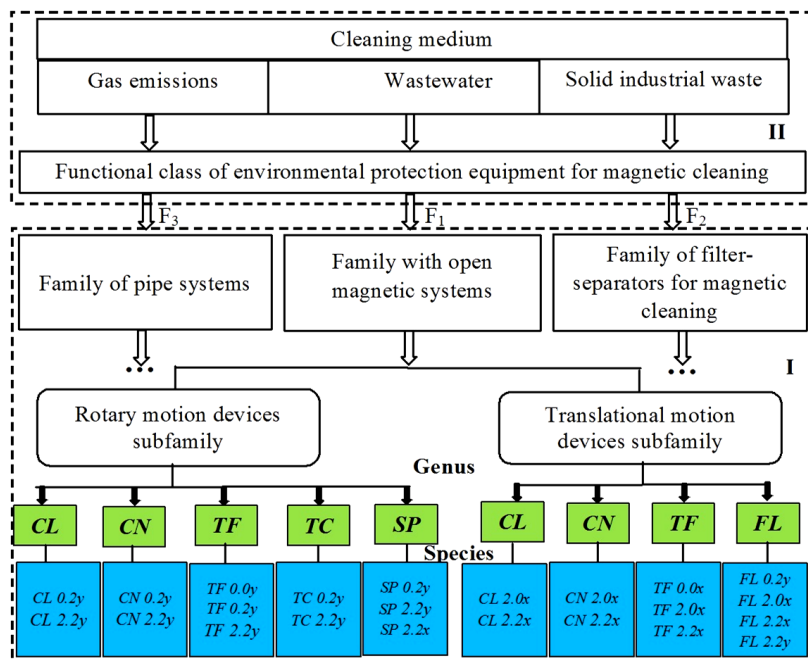


Fig. 7. Ranked structure of systematics of the functional class of EPE for magnetic cleaning

The proposed systematics ranked structure consists of two blocks: Block I contains taxa which are determined by the periodic structure of the genetic classification of the primary sources of the field; Block II – taxa, taking into account an artificial sign – a medium where the magnetic purification takes place.

Ranked systematics structure provides the basis for developing an information database on the structural diversity of EPE for magnetic purification. The ability to determine the full species composition of the functional class of EPE acts as a guarantor of completeness of information presentation.

**7. Discussion of research results**

At present due to the accumulation of large amounts of information the problem of systematization of knowledge is of particular relevance in any subject area. The level of system studies characterizes the degree of maturity of scientific disciplines. The focus of the results on addressing systemic problems is the undoubted advantage of the current research. The interdisciplinary nature of the research

is also important. It goes beyond the environment and requires knowledge of related areas, primarily from the field of electro-mechanics. Selected in the paper object of the study (functional class of magnetic separators) refers to the electromechanical power converters. In addressing the problem of genetic taxonomy of electromechanical facilities the priority was given to the ones owned by Ukrainian scientists. The work reviews only one functional class of devices for magnetic purification which can be considered a certain limitation of the work. In the future, it is necessary to extend the principles and methods of systematics to new classes of EPE.

In modern society, employers prefer specialists who are able to build efficiently their professional activities using the latest technology and devices. The results of the study can be used to create systematic catalogs, information and design databases and knowledge bases in the field of EPE. This will allow to avoid information overload, errors and unprofessional actions in the practice of environmental experts. Using systematic information in the learning process will contribute to the development of scientific systematic thinking, associative memory and professional intuition in students.

Presented in the paper results are a continuation of studies [8, 15] conducted towards solving scientific and applied problems of system design of magnetic separators of various kinds.

**8. Conclusions**

1. Compilation of information on existing methods and technical means of purification of gas emissions, wastewater and solid waste processing allowed to define the object of the study – the functional class of magnetic separators.

2. The concept of systematics for the studied functional class of EPE is developed that includes the purpose, theory and methods, conceptual apparatus, principles and results. The structural and systematic approach was applied to develop the systematics of EPE.

3. Analysis of the ranked structure of the systematics of EPE for magnetic purification with open work area showed that the structural diversity of devices of rotary and translational motion is represented by 5 and 4 families respectively. Subfamily of rotary motion devices is represented by 12 basic Species with axially symmetric sources of magnetic field. Species diversity of translational motion EPE subfamily for magnetic purification is sorted by 11 Types with the travelling field sources. Given the identity of the genetic information in such structures as FL 2.2x=FL 2.2y and SP 2.2x=SP 2.2y the total number of Species of electromechanical objects of the investigated class was 21. The taxa were added to the ranked structure of the genetic taxonomy (“Species”→“Genus”→“Subfamily”→“Family”) that take into account an artificial characteristic – an environment where the magnetic purification (of gas emissions, waste water, solid and industrial waste) is carried out.

## References

1. Sutherland, K. Choosing equipment: cleaning air and gas [Text] / K. Sutherland // *Filtration & Separation*. – 2007. – Vol. 44, Issue 1. – P. 16–19. doi: 10.1016/s0015-1882(07)70020-4
2. Prabhansu A review on the fuel gas cleaning technologies in gasification process [Text] / Prabhansu, M. K. Karmakar, P. Chandra, P. K. Chatterjee // *Journal of Environmental Chemical Engineering*. – 2015. – Vol. 3, Issue 2. – P. 689–702. doi: 10.1016/j.jece.2015.02.011
3. Leha, Yu. H. Shliakhy pokrashchennia ochyshchennia dymovykh haziv teploelektrostantsii [Text] / Yu. H. Leha, O. O. Mysliuk, N. M. Korneliuk // *Ekolohichna bezpeka*. – 2001. – Vol. 1. – P. 42–50.
4. Abma, W. R. Upgrading of sewage treatment plant by sustainable and cost-effective separate treatment of industrial wastewater [Text] / W. R. Abma, W. Driessen, R. Haarhuis, M. C. M. van Loosdrecht // *Water Science & Technology*. – 2010. – Vol. 61, Issue 7. – P. 1715–1722. doi: 10.2166/wst.2010.977
5. Ellouze, E. Cross-flow microfiltration using ceramic membranes applied to the cuttlefish effluents treatment: effect of operating parameters and the addition of pre – or posttreatment [Text] / E. Ellouze, R. B. Amar, A. M. Ben Salah // *Desalination*. – 2005. – Vol. 177, Issue 1-3. – P. 229–240. doi: 10.1016/j.desal.2004.12.010
6. Zhang, L. A review of current progress of recycling technologies for metals from waste electrical and electronic equipment [Text] / L. Zhang, Z. Xu // *Journal of Cleaner Production*. – 2016. – Vol. 127. – P. 19–36. doi: 10.1016/j.jclepro.2016.04.004
7. Zagirnyak, M. V. Magnetic separators [Text] / M. V. Zagirnyak // *Proceedings of the Seventeenth International Electrotechnical and Computer Science Conference ERK 2008, 2008*. – P. 7–8.
8. Zagirnjak, M. V. Magnitnye separatory. Problemy proektirovaniya [Text] / M. V. Zagirnjak, Ju. A. Branspiz, I. A. Shvedchikova. – Kyiv: Tehnika, 2011. – 224 p.
9. Oberteuffer, I. A. Magnetic separation: a review of principles, devices and applications [Text] / I. A. Oberteuffer // *IEEE Transactions On Magnetics*. – 1974. – Vol. 10, Issue 2. – P. 223–238. doi: 10.1109/tmag.1974.1058315
10. Svoboda, J. Magnetic Methods for the Treatment of minerals [Text] / J. Svoboda. – Elsevier, 1987. – 692 p.
11. Unkelbach, K. H. Magnetic separators mode of operation and applicability for the separation of materials [Text] / K. H. Unkelbach. – Köln: KHD Humboldt Wedag AG, 1990. – 87 p.
12. Zagirnjak, M. V. Razrobotka metoda opredelenija geometricheskikh parametrov jelementa matricy vysokogradientnogo separatora nanochastic [Text] / M. V. Zagirnjak, E. E. Volkanin // *Tehnichna elektrodinamika*. – 2014. – Vol. 6. – P. 24–29.
13. Bol'shoj jenciklopedicheskij slovar'. 2nd edition [Text]. – Moscow, St. Petersburg, 2000. – 1247 p.
14. Shynkarenko, V. F. Osnovy teorii' evoljucii' elektromehanichnyh system [Text] / V. F. Shynkarenko. – Kyiv: Naukova dumka, 2002. – 288 p.
15. Shinkarenko, V. F. Structural-Systematic Approach in Magnetic Separators Design [Text] / V. F. Shinkarenko, M. V. Zagirnyak, I. A. Shvedchikova // *Studies in Computational Intelligence*. – 2011. – P. 201–217. doi: 10.1007/978-3-642-16225-1\_11
16. Shynkarenko, V. F. Slovyk iz strukturnoi' ta genetychnoi' elektromehaniky [Text] / V. F. Shynkarenko, A. A. Shymans'ka. – Kyiv: NTUU «KPI», 2015. – 112 p.
17. Shinkarenko, V. F. Geneticheskij analiz i sistematika vidov asinhronnyh mashin postupatel'nogo dvizhenija (rod ploskih) [Text] / V. F. Shinkarenko, A. A. Avgustinovich // *Elektrotehnika i elektromehanika*. – 2003. – Vol. 4. – P. 92–100.