MINING MACHINERY, TRANSPORT, AND MECHANICAL ENGINEERING

Review article

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A systematic approach to the peat machines and equipment classification development

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Abstract
The «National Security Strategy of the Russian Federation until 2030» prioritises the use of resource-saving and waste-free technologies for natural resource extraction and processing, import substitution of mining equipment in the Russian mining sector, and the introduction of digital technologies at all stages of resource extraction and processing in the mining industry to improve their safety. The aim of the article is to study the gradual development of peat machinery classification and the relevance of its improvement through integrated mechanization devices to create waste-free extraction and processing of peat deposits using full-cycle mobile complexes with the development of environmentally friendly and resource-saving technologies for peat production. The methodological basis of the research includes post-event analysis, peat machine design theory, and systems analysis. As a research result, new system factors influencing the development of the classification of currently available machinery and equipment for peat production, as well as classification variants combining the processes of extraction and processing of peat deposit resources are provided, which allow modeling the structure of full-cycle mobile complexes for extraction and processing of peat deposit resources without waste. In terms of practical application, the classification of peat machinery enables the development of a rational decision-making data system for optimizing the structure of the technological machinery and equipment fleet of peat extraction enterprises, taking into account the deteriorating conditions of peat resources and development technologies, the economic conditions of the industry and the current trends of digitalization in the extractive industry.

Keywords
peat engineering, peat machinery, classification, system approach, methodology, design improvement directions, operating conditions

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ГОРНЫЕ МАШИНЫ, ТРАНСПОРТ И МАШИНОСТРОЕНИЕ

Обзорная статья

Системный подход к развитию классификации торфяных машин и оборудования

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Аннотация
В «Стратегии национальной безопасности РФ до 2030 г.» приоритетными направлениями являются: использование ресурсосберегающих и безотходных технологий добычи и переработки природного сырья, импортозамещение горной техники в горнодобывающем секторе РФ, а также внедрение цифровых технологий на всех этапах добычи и переработки сырьевых ресурсов в горных отраслях для повышения их безопасности. Цель статьи заключается в исследовании поэтапного развития классификации торфяной техники и необходимости ее совершенствования в связи с созданием средств комплексной механизации процессов безотходной добычи и переработки ресурсов торфяных месторождений с применением мобильных комплексов полного цикла с разработкой экологически безопасных и ресурсосберегающих технологий торфяного производства. Методологической основой исследования являются: ретроспективный анализ, теория проектирования торфяных машин и системный анализ.

В качестве результата исследования приводятся новые системные факторы, влияющие на развитие классификации имеющихся в настоящее время машин и оборудования торфяного производства, а также ее варианты, объединяющие процессы добычи и переработки ресурсов торфяного месторождения, позволяющие моделировать структуру мобильных комплексов полного цикла безотходной добычи и переработки ресурсов торфяной залежи. С точки зрения практического применения классификация торфяных машин позволяет разработать информационную систему для принятия рационального решения по оптимизации структуры парка технологических машин и оборудования торфодобывающих предприятий с учетом ухудшающихся условий эксплуатации торфяного месторождения, современного развития технологий разработки торфяного месторождения, экономического состояния отрасли и современных тенденций цифровизации в добывающих производствах.

Ключевые слова
торфяное машиностроение, торфяная техника, классификация, системный подход, методология, направления совершенствования конструкции, условия эксплуатации

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Introduction

During the peat industry development period in Russia until the 1990s, peat enterprises were distinguished by their large scale, peat deposits exploration areas, production volumes, human resources and a high degree of production processes mechanization. All the technical equipment of peat mines was made in Russia, and different types of peat machines were mass-produced every year. The range of peat equipment was quite representative, which required the creation of a special classification of peat machines and complexes [1–4]. Peat extraction machinery was subject to a separate production technical specifications and had its own system of designation. The designs of machines for peat extraction and processing were very diverse due to the large number of different methods and technologies of peat production.

Today's operating conditions in the peat extraction and processing industry dictate new demands on technological peat equipment and machinery. The designs of domestic peat machines and technological equipment complexes developed before the 1990s do not meet these requirements. This can be explained by the technical characteristics of the machines and the imbalance of the operating conditions, the insufficient level of automation, the imperfect design and the catastrophic decline in peat production [5, 6].

In the last 30 years the crisis came over the domestic peat machinery industry: the decrease in the volume of manufactured and sold products, the narrowing of the range of manufactured technological machinery and equipment and, as a result, the complete extinction of most peat machinery manufacturers or their adaptation another type of products with a stable demand (municipal, agricultural, forestry, construction, road, transport and other vehicles). A significant part of the peat machinery market is represented by expensive imported machines [7, 8].

During the Soviet period of development of peat science and technology the main centers were: the Moscow Peat Institute, the All-Russian Research Institute of Peat Industry (VNIITP), the Research Institute GIPROTORF. In 1958, the Moscow Peat Institute was transferred to Tver and became the basis for the Tver State Technical University. In 2010, VNIITP was dissolved, and since then the center for peat science and technology has become the Tver Peat School. Over the past 20 years, new scientific peat schools have emerged in Russia in St Petersburg, Yekaterinburg and Tomsk. Each of them has their own scientific perspective on many theoretical aspects of peat science and technology, from issues of geology and exploration of peatlands, development technology, classification of peat technology, to issues of economic, legal and social development of the industry. On numerous occasions, one can observe in articles on various peat topics that established scientific concepts are substituted, that definitions from other branches of knowledge are misused, that known phenomena are rediscovered, that scientists violate copyright, distorting the obtained data of primary scientific importance. Such substitutions are, in our view, unacceptable because they can cause scientific confusion and mislead. For example, a number of papers have appeared in the last 2–3 years in which the authors argue that there is no “single” classification of machinery and equipment for peat extraction and processing in the peat industry.

In implementing the classification of peat machinery, we believe it is important to explain how the development process of the scientific classifica-

tion of peat machinery and equipment proceeded. Why this process has been repeated and how the classification of peat machines has logically evolved over time and what classification features have been relied upon by the various authors is the purpose of this article.

Methodology of scientific views theoretical development research on the subject of peat machinery classification

The authors use a retrospective, critical analysis of the known classifications of peat extraction machinery to examine the theoretical development of scientific views on the classification of peat extraction machinery. The development of the design of machines that exploit peat deposits and extract and process peat resources is closely related to the methods and technologies used in the peat industry. The first peat machine was developed by I.F. Hoffman in 1843 [2, 4, 6], and since then there has been a rapid development of peat machines of various designs, which allow mechanizing partial operations of the technological cycle of peat extraction. It should be noted that the engineers and designers of peat machines often gave names to their machines, using their surnames (e.g. Sarmatov's shredding drum, Rogov's press, etc.). In 1931, at the Moscow Peat Institute, the scientific discipline "Peat Machinery» was established, headed by Professor M.I. Sarmatov, and the scientific course "Hydropeat process machines" was headed by Professor I.N. Glybovsky. In the 1950s, the Moscow Peat Institute was transferred to Kalinin (now Tver), and the Tver State Technical University became the center of peat science, where leading figures in peat science have worked to this day. Following scientists have specialized and specialize up to the present day in the peat engineering subject: M.V. Murashov, F.A. Opeiko, S.G. Solopov, L.N. Samsonov, L.O. Gortsakalyan, V.I. Tsvetkov, B.F. Zyuzin, V.F. Sinitsyn and others. Up to 1948, the term "classification» of peat machinery was not used, and only Professor S.G. Solopov in his book introduced this term for the first time, making an attempt to classify peat machinery. His classification is introduced in writing and presents peat machines in groups based on the principle of the extraction method and the course of the technological cycle of peat extraction. The emphasis is given to peat deposit development hydraulic method and dredging-and-hoisting machinery [6]. However, as the milling method of peat extraction became particularly popular in the late 1950s due to its high technical and economic indicators, the need arose to study the work of the main extraction machine – the milling drum (milling machine). Therefore, M.V. Murashov was the first to make a written classification of milling machines in his dissertation in 1964, based on the following principles: mining method; relationship to the wood inclusions milled in the deposit; technological purpose; design of the milling bit; design of the milling mold and mining elements. In addition, since the milling bit is the extraction machine directly involved in the extraction of peat from the peat deposit, special attention was paid to the interaction with the peat and wood inclusions. Thus, in the work of F.A. Opeiko [9] there is a tabular classification of crawlers and peat cutting equipment according to the number of degrees of freedom of the cutting elements and the type of operation performed. It is noteworthy that in the classification of F.A. Opeiko the development of the design of the peat machines is closely connected with the increase of the degrees of freedom of the excavation equipment. He also points out that the classification of peat machines based on the operations of the peat extraction cycle can not be uniform and clear enough, because one machine can perform several operations and have multifunctionality, or part of the operations, but one or another machine system can be out of order. It is worth mentioning that it was F.A. Opeiko who put forward the idea that with the increasing technical level of peat machines and the complexity of calculations in their design, it is necessary to take into account not only the experimental data of their work, but also "*...the possibilities of modern simulation and digital computing devices*". And exactly with the above-mentioned statement of F.A. Opeiko in 1968 began the automation process and the use of digital devices in the design and control of peat machines, the centralization of the design process and control in the management of peat companies. This direction founding fathers can be rightly considered the representatives of the Tver peat school [10]: N.M. Karavaeva, A.I. Burakov, V.I. Kuznetsov, A.N. Volkov, G.A. Dmitriev, B.V. Palyukh. The development of peat machinery is complicated by the complications of extraction, geological and climatic conditions, and the development of technologies for peat extraction, especially the mechanization of peat production, integrated mechanization, automation, and digitalization (Fig. 1).

The next milestone in the development of peat machine classification is considered to be the work of Professor S.G. Solopov in 1972 [11]. This is the second modification of the classification he developed in 1948, which differs in that the terms "complex" and "complex unit" appear in it, which no one has ever used in peat engineering. Basically, Professor S.G. Solopov has developed three peat machinery classifica-

tions, but his work of 1981 [12] lacks a complex unit for drying peat on sieves in a stack. Peat machines in his classifications are grouped by the type of dry peat (lumpy and milled crumbly peat) and by the technological process operations of the peat deposit development.

Considering the development of the economic use of peat in the Soviet period and today, almost every year scientists develop new types of peat products that require a different degree of processing of the original peat raw materials. Therefore, the need to classify peat processing equipment arose, and in 1990 Professor O.S. Gorfin was the first to develop a classification of equipment for peat processing plants [13]. By the beginning of 1990, most of the peat deposits in the regions of the European part of Russia had been mined, peat extraction and geological conditions were deteriorating, leading to a decline in the quality of the peatlands affected by the development. One of the most important quality indicators of peat deposits, in addition to the degree of decomposition, is the degree of stumpage. The higher the percentage of buried wood in the deposit, the lower the productivity and quality of peat extraction (stratification and surface extraction or deep extraction). In this context, B.F. Zyuzin in 1989 in his work [14] gives a detailed classification of peat mills, considering them as the main driving element of peat extraction machines. Changing economic conditions in Russia and the sharp decline in peat mining have led to the need to develop new technologies for peat extraction and processing. And for this reason, in 1999, Professors L.N. Samsonov and V.F. Sinitsyn improved the classification of peat machines proposed in 1981 by Professor S.G. Solopov. Also known is the classification of Professor V.D. Kopenkin from 2002 [15], in which he combines the classification of mining machines and the classification of the main structural elements of peat machines and complexes. At the same time, he proposes to consider peat machinery as a subclass of mining machinery and equipment and uses the term "geomachinery". The peculiarity of the classification of V.D. Kopenkin is that on the basis of the study of the classification of mining machinery, he proposes to use some of them (heavy crawler dozers, excavators) for the development of peat deposits. He refers to the lack of available Russian peat machines and the use of quarry machines abroad [16–19]. Therefore, it is necessary to present the course of the history of development of the classification of peat machinery in a graph prepared by the authors according to the method of V.D. Kopenkin to study the flow of scientific information on the subject of classification of peat machinery and equipment (Fig. 2).

As can be seen from Fig. 2, the development of views on the peat machines and equipment classification has a long history and three stages of scientific development (segments: A, B, C), which are closely connected with the changing conditions of peat enterprises industrial and economic activity, namely: economic, mining and geological and technological, related to the improvement of peat deposits development methods and technologies (geotechnology). And each subsequent classification was an improved

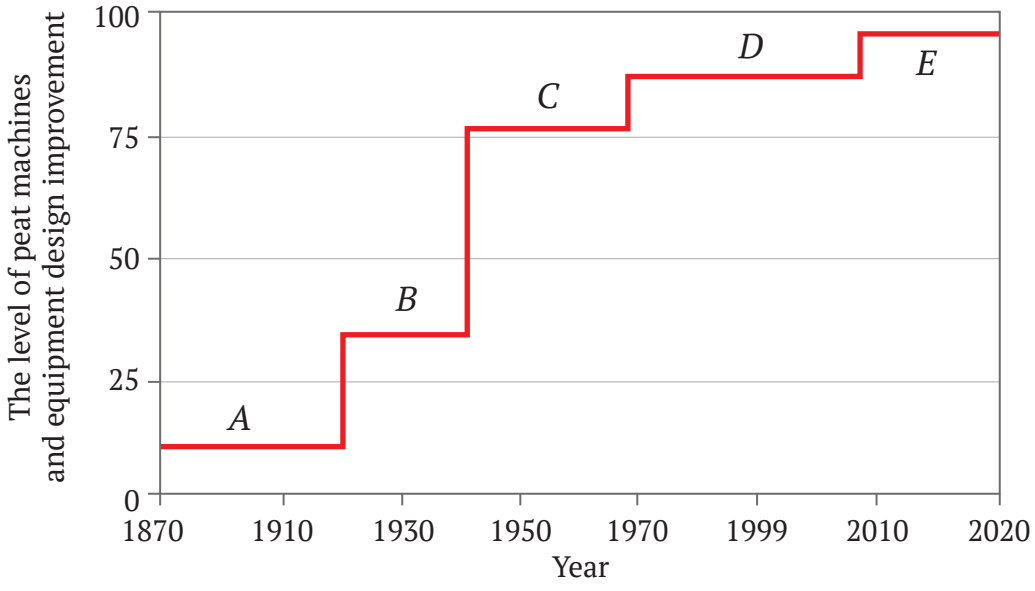

Fig. 1. Levels of peat machinery designs improvement (compiled by the article authors):
A – partial mechanization; *B* – mechanization; *C* – comprehensive mechanization; *D* – partial automation; *E* – automation and partial digitalization

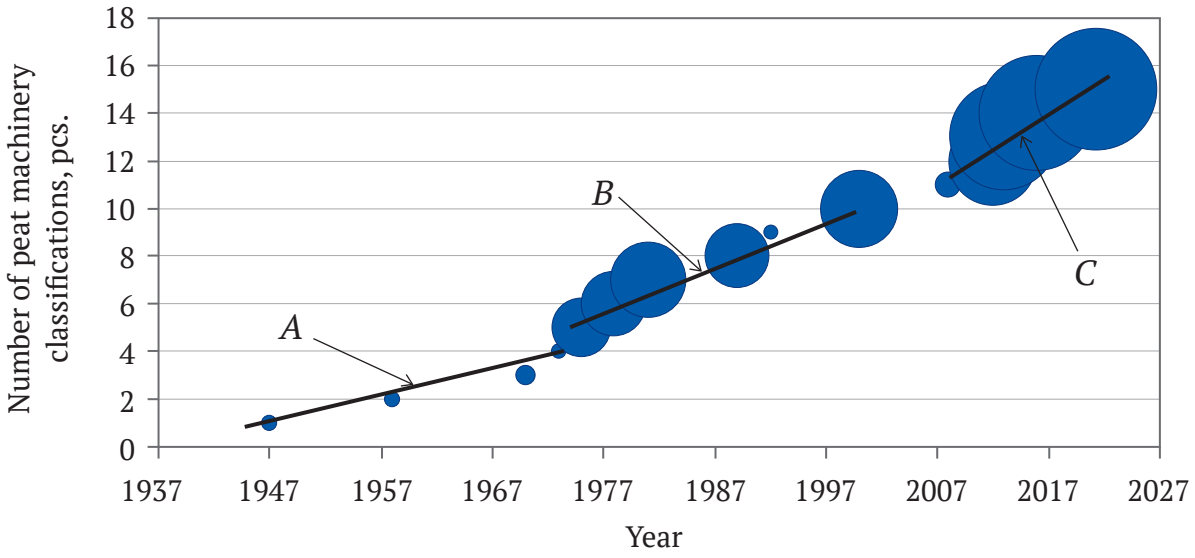

Fig. 2. Peat machine classifications development (compiled by the article authors)

modification of the previous one (marked by large circles). Some of its structural elements (indicated by small circles) depend on the development of the working tools and the chassis of the peat machines and represent separate scientific fields. The aim of these directions manifests itself in a thorough and detailed study of the interaction processes of the working elements of peat machines with the peat deposit, which has various geological, structural, physical-mechanical and hydrodynamic characteristics. The last (third) phase of the development of academic interest in the classification of peat machinery began in 2012 and is characterized by the introduction of selective geotechnologies for peat extraction using hybrid, universal, mobile and autonomous complexes of peat machinery and equipment determined by the trend of digital transformation of technological processes in the extractive industry [20–22].

Using a systematic approach to the development of a peat machinery comprehensive classification

Classification is a general scientific method of knowledge systematization aimed at organizing a certain combination of studied objects from different areas of reality, knowledge and activity into a system of peer groups (classes) in which these objects are distributed on the basis of their similarity in certain essential properties. The Great Soviet Encyclopedia defines classification as "a system of subordinate concepts (classes of objects) of any field of knowledge or human activity, often presented in the form of schemes (tables), which serves as a means of establishing connections between these concepts or classes of objects, as well as for precise orientation in a variety of concepts or corresponding objects". The classification main tasks consist in fixing relations and patterns between objects that have the same properties, as well as storing and retrieving data. In this regard, any classification can be seen as a database prototype. From this point of view, classification enables the development of science and machines, starting with the accumulation of theoretical knowledge and ending with their systematization. Classification, based on sound scientific knowledge, makes it possible to identify the actual state of science, machinery or its structural elements and to evaluate their development appropriately [23–25].

To develop peat machinery classifications, the authors used the system approach principles and methods. The system approach makes it possible to reveal the object integrity by defining various relations, which form a comprehensive and integral view of the object under study. From the system approach point of view, classification is a complex ordered system of elements, united by structural links to achieve a certain objective (Fig. 3).

System analysis allows affirming a strong connection between peat production technological machines, peatland exploration conditions and peat extraction and processing technologies [26, 27]. The change and improvement of peat extraction technologies leads to the need to develop new machines and improve their design. Thus, the factors affecting the development of peat resources extraction and processing technologies have a direct impact on the design of peat machinery and the completion of technological complexes [28, 29].

Research results discussion

The analysis of Fig. 3 shows that the classification of peat machines is constantly improving due to the influence of objective system factors. These factors include: the development of peat geotechnologies, the improvement of peat machinery design to improve its performance characteristics, the cheapening and import substitution, the development of modern mining machinery, the deterioration of mining, geological and climatic conditions of peatlands, and economic, legal and organizational conditions. Taking into account the listed factors, four modifications of the peat machine classification have been proposed by article authors since 2012, each of which is the logical continuation of the previous one and is presented in the published works [2, 4].

The classification of peat machines in the 2012 article [4] was developed based on the type of peat deposits extracted. This classification for the first time distinguishes "peat-wood raw material" as a separate type of raw material, and thus the structure of peat deposit raw material includes: peat; woody raw materials obtained during the consolidation of woody vegetation in the technological process of preparing the peat deposit for development; peaty and woody raw materials obtained in the technological process of deep (continuous) peat extraction together with woody vegetation growing on the peat surface and buried wood in the thickness of the peat mass.

In view of the similarity of the technological process of peat deposit preparation for development with the similar processes in other nature exploitation branches (for example, mining, logging, etc.) and the absence of mass production of peat machinery in Russia the authors include in the classification the machines of the forestry, mining, agricultural, construction and road complexes. This allows to derive a new definition of peat complexes – "Mixed complexes".

The classification of peat machines in the work [4] differs, as new features are taken into account – "peatland development conditions» and "type of production organization", which allow to filter out new machine complexes: "mobile peat machines for on-site peat extraction and processing» and "energy self-sufficient peat complex". The 2020 classification shown in Fig. 4, complexes have been added to distinguish equipment for the safe storage of peat, wood, peat-tree raw materials; mobile processing, loading, transportation and receipt of peat and peat-tree resources.

In the context of the outlined global tendency of the transition of mining industries to the ideology of Mining 4.0, complication of economic-political and mining-geological conditions for the development of peat deposits and the need to optimize the range of peat products, as well as the use of selective geotechnologies, the authors introduce the principles of peat classification into a new complex classification: "complexity of technology for the development of peat deposits", "degree of mechanization, automation and digitalization of peat technology processes". Given principles made it possible to distinguish "Hybrid and selective geotechnologies" and the corresponding "Peat machines hybrid complexes", which imply automated, autonomous, robotic and digital control. Such "Hybrid complexes" will allow peat production to enter the digital transformation era of extraction and processing technological processes of peat deposit raw materials [5].

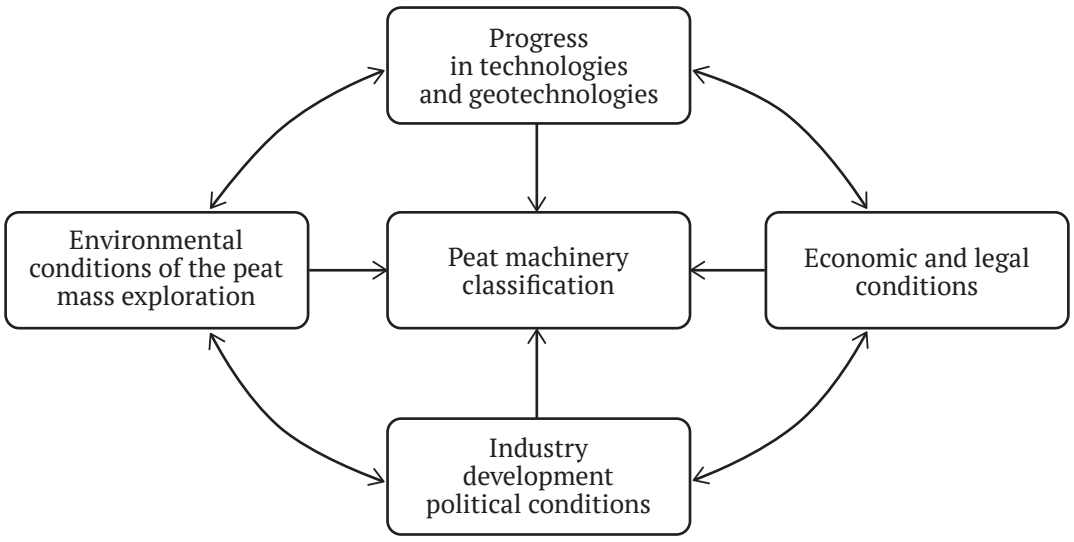

Fig. 3. Systemic factors influencing the peat classification development (compiled by the article authors)

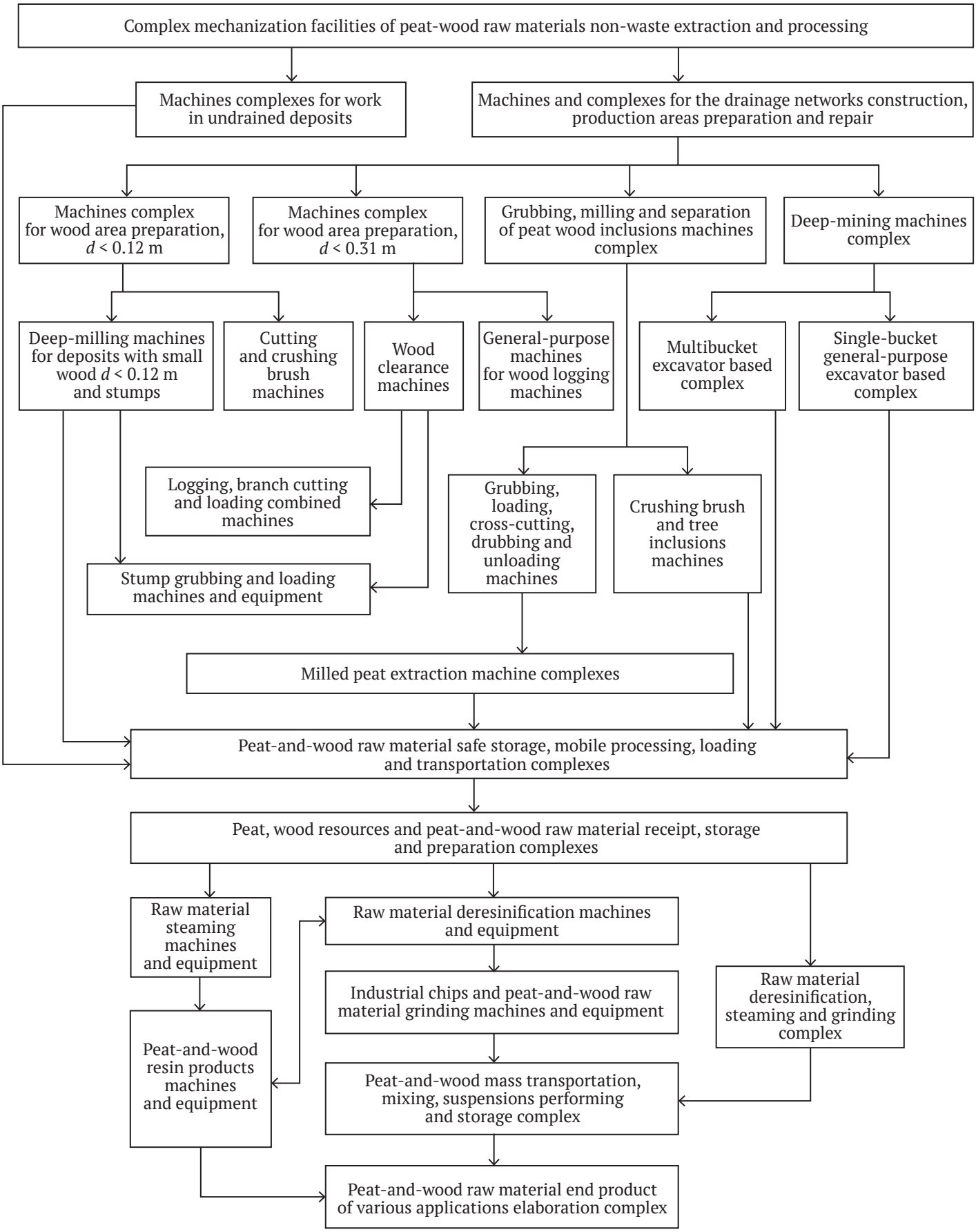

Fig. 4. "2020 Peat Machinery Classification" segment for the peat-and-wood raw materials production (compiled by the authors)

Conclusion

As a result of the research, the authors made the following conclusions:

1. The classifications of all peat machines have been developed according to the main law of connection between the technological equipment and methods of exploitation of peat deposits and the production cycles of peat extraction and processing.

2. In the classification proposed by the authors, due to the development of scientific views on the problem of selective peat deposits and the deterioration of the conditions of development of peat deposits, the principle of "Hybrid complexes» was introduced.

3. The authors point to a new type of peat raw material – the "peat-and-wood raw material" – which consists of buried wood, stumps, that were considered waste in the peat development of traditional technologies, cleared and sent to the landfill and then processed into low-grade firewood.

4. The obtained peat-and-wood raw material requires a new type of equipment. Therefore, the authors introduce the principle "Type of obtained raw materials" into the classification.

5. Considering the mining digitalization development, the authors introduce the principle "Peat technological processes mechanization, automation and digitalization levels" for the peat machines classification.

6. Since in Russia the peat machine building market is represented mainly by foreign machinery, and domestic peat machines are custom-built, the authors suggest using machines from other nature-operating branches with similar working principle (mining, logging, agriculture sector et al). In view of this, a new term may appear in the classification of peat machinery, characterizing the improvement directions of geotechnologies for the development of peat deposits – "mixed (hybrid) complexes and technologies".

7. There are two vectors of the peat machinery classification development: 1. according to the technological process of the peat deposit development, performed operations type and received raw material type (peat crumbs, grains, lumps, hydromass, peat-and-wood raw material, peat water, off-grade wood, peat dust, wet peat (dry peat)); 2. according to the structural elements type (classification: chassis, working tools, engine type, drive type, control type, et al.).

8. From a system approach perspective, the authors believe that the peat machinery classification should not be constant. It should dynamically develop under the influence of the factors acting on it, allowing to predict and foresee the possible directions of the peat machinery complexes development.

9. Since the peat machinery classification is systematic, was developed and evolves under the influence of the system factors affecting it (for instance, various technological sanctions, the Russian state industries digital transformation program, "neutral carbon footprint" technology, "green technologies"), then, considering Mining 4.0, further design improvement of all types of peat complexes will become more complicated due to the introduction of the artificial intelligence and IT technologies elements in the peat machines design.

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