Structure modeling of mining machinery systems for production of raw peat materials

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Abstract. This work describes systems of mining machines for peat extraction, particularly, the systems that exploit environment-friendly technologies. An algorithm for schematic structure modeling of modular mining machinery systems was introduced and analyzed. Based on the analysis, an algorithm for assessing energy consumption of an entire machinery system on the basis of its structure was described. As an example, structural schemes of four modular mining machinery systems were assessed. These structural formulae were also used for structuring mining machinery systems by the energy efficiency criterion. Effectiveness value of mining machinery system is suggested to be assessed by energy efficiency coefficient. The results of the analysis and assessed models proved the viability of mining machinery systems for open-cast peat winning that combine the modules of extraction, processing, transfer, and others organized by applying devised structural formulae and energy efficiency criterion.

1. Introduction

Peat is a natural renewable biological source of energy. It has an advantage over hydrocarbons, as its combustion emits no sulfur, so it is more environment-friendly [1].

In the contemporary rapidly developing mining industry, there are three main approaches to peat extraction, two of them are used in quarrying and another one is applied to surface layer extraction. Peat can be extracted using various methods: excavation, loosening, or hydraulic extraction. Choice of the method depends on various factors, including conditions at a deposit [2].

Surface layer extraction is a traditional peat winning strategy, it is performed through loosening. This requires lowering of the water level that makes it possible to repeatedly extract thin layers of peat. The process of surface layer extraction includes the following steps: milling of the upper layer, turning of the upper layer of milled peat, ridging of dried peat, collection of ridges, peat stacking, peat isolation in stacks [3]. Primarily because of significant lowering of the water level, this way of peat extraction harms flora and fauna in the area of the deposit, and that can be compensated only through recultivation [4]. Moreover, peat milling is associated with significant labor and economic costs, the latter arise from the ground lease. It takes approximately 2 years to prepare a deposit for extraction [5]. As peat is dried on fields, the drying process restricts extraction to a specific season, requires large areas, and increases the risks of fires [6].

The drawbacks of traditional peat extraction and deteriorating state of environment require the application of innovative environment-friendly technologies, which is impossible without new systems for peat extraction and processing [7].

2. Environment-friendly systems for peat extraction

Effectiveness of a system for peat extraction is based largely on its elements and links between them. Modern market sets demanding requirements that can be hardly met without the right choice of peat extraction systems and good process flow design. Today, technological solutions for peat extraction that, for example, do not rely on large areas to operate properly, seem to be very prospective, as they help to reduce operational costs, in this case, the cost of ground lease [8]. Therefore, the development of technologies for peat quarrying is of high relevance today, as this strategy of peat extraction allows...
one to operate the peat layer at a time, and afford working at significantly smaller operational area, in comparison to the strategy of surface layer extraction. It is necessary to note that typically peat quarrying implies excavation of peat at preliminary prepared deposits with the lowered water level, so the application of the peat quarrying strategy bears many of the drawbacks of surface layer extraction [9]. Today, scientists introduce technological solutions that allow performing extraction without preliminary water level lowering. Such machines include walking bridges or platforms that are used as bases for deployment and operation of mining machinery in natural environment of a deposit [10].

Patent RU 2614337, for example, suggests the construction of a dam around mining machinery that allows it to operate at liquid ground skipping the step of water level lowering. This dam can also be used as a base for a hangar that allows performing year-round production. Still, this peat winning technique requires extensive preparation that includes preparatory extraction, processing, and construction of the dump. Peat extraction system used in this method is quite complex and metal-consuming [11].

Some solutions use floating platforms to perform peat extraction from water surface of the deposit, making it possible to operate without preliminary water level lowering. Patent RU 2599117, for example, describes a system for peat extraction deployed at floating platform. Extraction is performed by excavation of the peat at full thickness of the peat layer. Machinery that is used in this method is a double-jaw digging grab deployed at the floating platform. It is important to highlight that these floating platform are highly metal consuming and for their operation it is required to prepare the water zone of the deposit [12].

Another way of peat extraction is the use of a system that combines various mining machines deployed on moving platforms. The platforms are brought to motion by a tractor. Patent RU 2304721, for example, describes a system of peat extraction machines deployed on a platform built of hulls. These platforms can extract peat without preliminary lowering of the water level. There is a rod that clutches platform with an off-road pull-tractor that moves across preliminary prepared deposit. Peat is extracted through the deposit washing with water jets. The pulp is then transported under pressure via pulp line [13].

There is another prospective way of peat excavation. Patent RU 2684269 suggests the use of moving bridges with excavating machinery. This system can operate without preliminary lowering of water level. At least three parallel ditches are required. Peat is extracted from the space between ditches. Peat is extracted by laterally moving working body. Peat is excavated from pristine surface of peat deposit that has a radial ditch border. Bridge moves on two carriages. One carriage should be located closer to the center of the radial deposit, so the bridge could 'whirl' around the centre. Carriages are monorails mounted. Monorails are installed at the flooring that rests on pales put in parallel ditches. Then, extracted peat is transported to the land for further processing. Ditches are formed by two single-bucket mechanic arms that serve as pull shovels. Working body hanging from the bridge can be made in form of either a milling screw or a backhoe. Raw peat is transported by barges to the land where it undergoes further processing [14].

3. Structural formulae of peat extraction systems

Systems of machines for peat extraction and preparation of peat products for sale can include combined or separated systems for peat extraction and processing, drainage, deposit preparation, recultivation, etc. Systems themselves consist of modules, e.g. module for drying, separation, etc.

Structural formulae of peat extraction system can include the following modules for extraction (EX), processing (PR), drainage (DR), separation (SR), drying (DG), final product preparation (FPP), energy generation (EG), transportation (TR).

There are three types of links between machines comprising a system: coordination, connection, and coupling. These links connect modules too.

(-) refers to ‘coordination’. We speak about coordination in case when each element has its own parameters, restrictions and construction. Elements are coordinated towards a share goal;

(+ ) refers to ‘connection’. We speak of connection when two elements with their own construction acquire shared parameters and restrictions, thus forming a single new element with its own functions and restrictions;
Combining elements, modules and links in different sets can result in different technological solutions best applicable for exact operating conditions [15]. Formulae examples can be found below.

First, we would like to demonstrate a structural formula of milled peat extraction system. We will refer to this system as a basic one. There is a 'connection' link between first three modules (extraction, transportation of equipment and resources). Although these modules are not physically connected, they share the same resource flows that, if being disrupted, may prevent meeting the shared goal. Other modules are linked by 'coordination', as every element of the system has no shared parameters with other, except for the same goal to meet [16].

Traditional milling (typical of surface layer extraction):

\[ \text{EX}_{\text{mg}} = \text{EX}_{\text{mg}} + \text{TR}_{\text{eq}} + \text{TR}_{\text{eq}} - \text{SD} - \text{SR} - \text{DG} - \text{FPP} \]

\[ = (M_{\text{mg}} + F_{\text{dg}}) + (M_{\text{eq}} + F_{\text{eq}}) - (M_{\text{sd}} + F_{\text{sd}}) - (M_{\text{sr}} + F_{\text{sr}}) - (M_{\text{dg}} + F_{\text{dg}}) - (M_{\text{fpp}} + F_{\text{fpp}}) \]

\( \text{EX}_{\text{mg}} \) refers to milling extraction module;
\( \text{TR}_{\text{eq}} \) refers to transportation of equipment;
\( \text{TR}_{\text{eq}} \) refers to transportation of resources;
\( \text{TR}_{\text{eq}} \) refers to transportation of extracted material;
\( M \) refers to mechanical part that brings an element and/or its constituents to motion;
\( F(e)g.d \) refers to force generated when energy of one type, 'e' is electric, 'h' is hydraulic, and 'd' is internal combustion engine converts into work.

Indices of mechanical parts and forces correlate with appropriate modules.

Next, we will translate into structural formula a floating platform for deploying mining machinery described in Patent RU 2304721. The difference between this solution and one for milled peat extraction is in its links. This system includes various types of links that inter-connect its elements. As modules of extraction and equipment transportation are designed as connected (the tractor and the platform with equipment are connected by rod), the formula includes this type of link (connection). Module for resource transport (pulp line) is 'connected' with extraction module, so there is also link of materials transportation (TR_{mch}).

\[ \text{FA}_{\text{mg}} = \text{EX}_{\text{mg}} + \text{TR}_{\text{eq}} + \text{TR}_{\text{eq}} - \text{SD} - \text{SR} - \text{DG} - \text{FPP} \]

We also suggest formula for peat excavation from prepared deposit. Extraction can be performed using excavators and raw peat can be further transported by automotive transport. As modules for extraction, equipment and resource transportation are combined in the excavator, there is a link of 'coupling' type between them. Automotive transport for peat materials transportation is separated from the system and has its own parameters. This module shares only the common purpose with other elements of the system, i. e. the type of the link between this module and other elements is 'coordination'.

Excavation from the prepared deposit (traditional for peat quarrying):
efficiency criterion \( C_{\text{eff}} \) of given mining machinery systems. This criterion can be calculated through one of the structural formulae, by inserting numerical expressions of each machine's parameters, including efficiency coefficient. Generally, efficiency coefficient is calculated upon the ratio of work done to extract particular amount of peat using particular system \((\Sigma W_{\text{eff}})\) to work done to extract the same amount of peat using the basic technique \((\Sigma W_{\text{b}})\). In this paper we used extraction through milling as the basic technique [18]:

\[
C_{\text{eff}} = \frac{\Sigma W_{\text{eff}}}{\Sigma W_{\text{b}}}.\]

The system with the moving bridge described in Patent RU 2684269 uses the hydraulic excavator with interchangeable attachments as a track grader. Based on analysis of various types of hydraulic excavators, we estimated its approximate digging and loading capacity in m³/hr: \(\text{Cap}(EN)_{\text{ex}}\). In nominal capacity, the function can be approximated by the following function [19]:

\[
\text{Cap}(NC)_{\text{ex}} = -0.015\text{Cap}^3 + 2.16\text{Cap} + 12.4.
\]

\( NC \) refers to nominal capacity of the excavator engine in kW. Assessment of power consumption in the function of preset capacity shall be expressed as [20]:

\[
q_{\text{ex}} = 2.16 + (198 - 4.44q)^{0.5}
\]

\( q \) refers to the volume of the bucket in m³.

Functions for pale putting \((NC_{\text{expp}})\) and flooring and track laying \((NC_{\text{exit}})\) are akin to the previous ones. Alike functions, although devised through calculations, can include work done while transporting pales and flooring materials \((NC_{\text{Treq}})\) and peat materials \((NC_{\text{Treq}})\), moving bridge \((NC_{\text{emmch}})\), drive of the miller \((NC_{\text{Treqchq}})\), and while transporting extracted raw materials \((NC_{\text{Treqchq}})\). Given the operating time of all the elements, efficiency coefficient can be calculated using the following formula [21]:

\[
C_{\text{eff}} = \frac{\sum(2NC_{\text{ex}} + NC_{\text{expp}} + NC_{\text{emch}}/HR + NC_{\text{Treqchq}} + NC_{\text{Treqchq}})}{\Sigma(NC_{\text{emch}}/HR)}/\Sigma(NC_{\text{emch}}/HR).
\]

4. Conclusion

According to the results of the analysis of existing modern technologies, the prospective new system of peat extraction machinery will be designed to operate at natural pristine deposits while exploiting the peat quarrying strategy. Application of structural formulae and combining composite modules for peat extraction, processing and transportation makes it possible to outline the design of the future system. The efficiency coefficient calculated through structural formulae makes it possible to assess the viability of a particular combination of modules and to compare them with already existing machines.

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