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11 HYBRID DRIVES AS A WAY TO EFFICIENT ROAD CONSTRUCTION

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ABSTRACT

Effective use of means, including financial ones, in today's realities is the primary task of every region, every industry, every enterprise. Taking into account the scale of destruction of the road complex caused by military aggression, this task is particularly urgent. One of the methods of such savings in road construction is the use of hybrid drives. The impact of modern technologies in the field of creating hybrid drives on increasing the effective construction of the road construction complex as a whole is considered. The strategy for the development of hybrid drives of earthmoving machines (EMM) is considered on the example of the world's leading manufacturers of equipment. An analysis of the structural performance of the power drive as a whole and its individual elements, the interaction of power plant units in different operating modes is given.

KEYWORDS

Hybrid drive, machine, cycle, efficient construction, energy, process.

11.1 ECOLOGICAL APPROACH IN ROAD CONSTRUCTION

For the last ones years question ecological security, in the perspectives of growing consumption hydrocarbons sources of energy, is particularly acute [1–3]. It is testified by the data of research by quantity of CO_2 emissions at construction of roads and infrastructure by different ministries of transport and infrastructure in the world (**Fig. 11.1**).

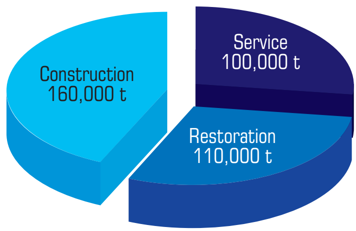


Fig. 11.1 Annual CO_2 emissions at construction of roads and infrastructure
Source: author's development

In this regard, the use of machines and equipment with high indicators of fuel economy and environmental safety, as well as the modernization of machines in operation, can be one of the most effective means of improving the fuel, energy and environmental situation [4].

Such machines are machines with hybrid power plants. Hybrids have been widely developed in the automotive industry, which cannot be said about earthmoving machines.

According to research, gasoline and diesel engines consume a large part of oil products. The average efficiency of engines is only 23 % (gasoline engines – up to 21 %, diesel engines – about 25 %) [3, 5]. Therefore, a large part of oil products is burned in vain and causes damage to the environment – it goes to heating and polluting the atmosphere. But this is far from a complete description of the efficiency of the machines. Its main indicator is not the efficiency of the engine, but the load factor. Unfortunately, earthmoving machines use powerful engines extremely inefficiently. Their engines are designed for heavy loads, but during the operation of the machine, they do not always reach the maximum. Car manufacturers in Germany, the USA, Japan, China, Sweden and other countries are trying to solve this problem in their own way by switching to gas fuel, switching to electric cars, installing a special absorber of harmful combustion products on each car and burning them in the muffler, optimizing the working process due to the improvement of the operator's qualifications, as well as redistribution of engine power, accumulation of underutilized power and its subsequent use in loaded operating modes.

For example, the VOLVO company [6] works in the field of improving energy efficiency in the following directions (**Fig. 11.2**).

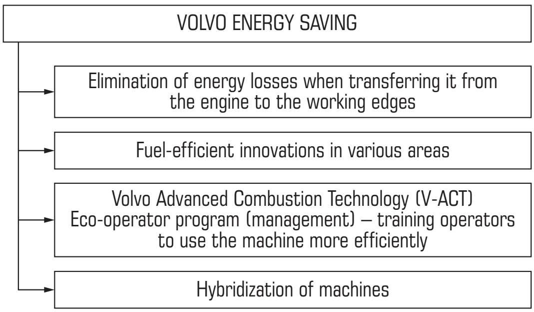


Fig. 11.2 Strategy of increasing energy efficiency of the VOLVO earthmoving machines
Source: author's development

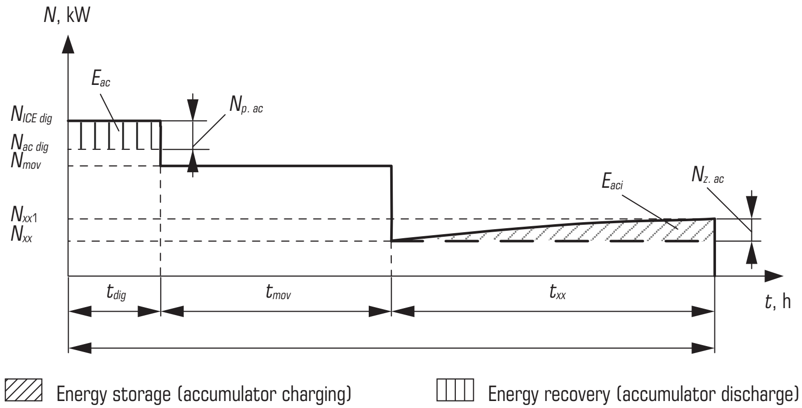
As is known, electric hybrids have become widespread in the automotive industry. Thanks to the modern level of electrical engineering and electronics, it has become possible to create computerized energy converters of fairly small mass and cost, which is largely compensated by the advantages of an automated drive from the point of view of improving fuel economy and reducing the toxicity of exhaust gases of the internal combustion engine, which is part of the hybrid power plant. However, these system data assume the presence of energy sources for charging the batteries.

This condition is not always feasible for earthmoving machines, because most often they work in field conditions. Also, due to their large capacities, the volume of batteries and their charging time have increased significantly. Therefore, manufacturers are looking for other ways to increase the fuel efficiency of earthmoving machines.

With the help of hybrid systems based on fuel cells, as on Hino trucks. When the main unit of the hybrid installation is a 4-cylinder diesel engine (with turbocharging and a Common Rail fuel supply system) with a power of 110 kW and a torque of 420 Nm at a crankshaft rotation frequency of 2500 and 1400 min^{-1}, respectively, combined with an electric motor – an alternating current generator with a power of 36 kW and a torque of 333 Nm [7].

Since these machines are most often hydrofied, it is rational to use hybrid units based on hydro-pneumatic accumulators, which allow to accumulate hydraulic energy when the machines are idling and return it during loaded operating modes [8, 9] (**Fig. 11.3**).

When using a hydro-accumulating system in the work cycle of the bulldozer, energy flows will be redistributed and the step-by-step consumption of engine power will change [10].



E_{ac} – energy consumed by the accumulator during the digging stage; $N_{p.ac}$ – the power consumed by the accumulator during the digging stage; E_{aci} – energy accumulated at idle speed; $N_{z.ac}$ – power accumulated at idle speed; $N_{ICE.dig}$ – the power of the internal combustion engine during digging without the use of a hydraulic storage system; $N_{ac.dig}$ – diesel engine power for digging operations using a hydroaccumulating system; N_{mov} – capacity of the diesel engine to move the soil; N_{i1} – the power consumed at idle when using the hydroaccumulating system; N_i – power consumed at idle speed without the use of a hydroaccumulating system; t_{dig} – time of soil digging operation; t_{mov} – soil movement time; t_i – idle time; t_C – the working cycle time

Fig. 11.3 Cyclogram of the working process of a bulldozer using a hydraulic storage system
Source: author's development

11.2 TECHNICAL COMPONENT IN THE CONTEXT OF EFFECTIVE ROAD CONSTRUCTION

By definition, a hybrid car is a car that uses more than one source of energy to drive mechanisms. Since the hydroaccumulating system (HAS) is the drive of the working equipment, the machines equipped with such systems can be called machines with hydrogenated hybrid power plants (MHHPP).

Theoretically, the installed power of the engine of the hydraulic machine can be reduced by the amount of power accumulated by the hydroaccumulating system, which can be accumulated in the idle modes of the machine, during its braking, lowering of the working equipment, etc. [11], as well as due to the improvement of the hydraulic storage system itself:

$$N_{EICE} = N_{ICE} - N_{HS}, \tag{11.1}$$

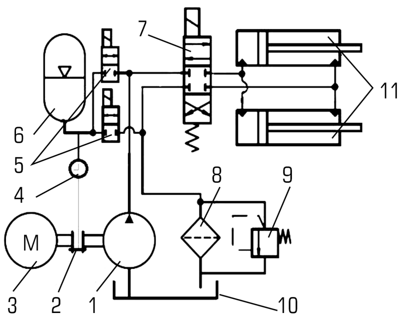
where N_{EICE} is the power of the MHHPP engine; N_{ICE} is the power of the engine laid down during the design; N_{HS} is the capacity of the hydroaccumulating system.

Thus, a detailed study of energy flows in the working cycle of machines, research of ways to accumulate underutilized energy will allow to more evenly load the primary engine and reduce its installed power, which will lead to an increase in fuel economy and environmental safety [12].

The HAS improvement is possible due to the installation of controlled couplings between the primary engine and the hydraulic pump [12, 13], which allow it to be turned off in unmarried modes of operation (**Fig. 11.4, 11.5**).

The use of a controlled clutch in the hydraulic storage system will allow to reduce the energy consumption of the primary engine, and therefore the fuel consumption, in idle modes of operation and in loaded modes using the hydraulic storage system [14].

Experimental studies were conducted to increase the fuel efficiency of machines when the hydraulic pump is turned off, using the T-40 tractor as an example. The results of which are summarized in **Table 11.1** of technical and economic indicators.



1 – hydraulic pump;
2 – controlled clutch;
3 – internal combustion engine;
4 – pressure sensor;
5 – hydraulic distributors for controlling the HPA charging-discharging process;
6 – hydro-pneumatic accumulator;
7 – hydraulic distributor;
8 – filter;
9 – safety valve;
10 – tank;
11 – hydraulic cylinders of control of working equipment

Fig. 11.4 Scheme of the MHHPP with a controlled clutch
Source: author's development

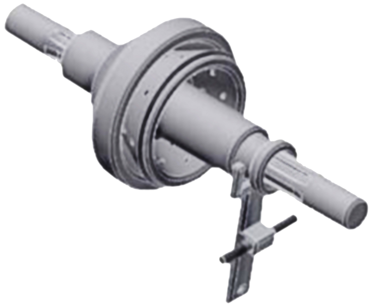


Fig. 11.5 3D model of the MHHPP clutch
Source: author's development

Table 11.1 Technical and economic indicators of the studied bulldozers

Indexes	Marking	Indicator value				
		Bulldozer without HAS	Bulldozer with HAS	Increasing the efficiency of a bulldozer with HAS, %	Bulldozer with HAS and controlled clutch	Increasing the efficiency of a bulldozer with HAS and a controlled clutch, %
Engine power, kW	N	66	66	–	66	–
Productivity, m^3/h	P	50.52	53.06	4.78	62.8	4.78
Bulldozer mass, t	G	7.185	7.220	–	7.23	–
Specific energy intensity of digging, kW/m^3/h	N/A	1.3	1.2	7.69	1.05	7.69
Specific material capacity, t/m^3/h	G/P	0.14	0.13	7.14	0.11	7.14
Total fuel consumption, l/shift	Q	47.3	45.6	3.59	42.8	9.59
Specific fuel consumption, l/m^3	q	0.14	0.12	14.28	0.12	14.28
Generalized indicator, kW·t/(m^3/h)^2	$I_{NG}=\frac{NG}{I^2}$	0.185	0.169	8.64	0.12	8.64
Specific fuel consumption per unit of power, l/shift/kW	Q/N	0.71	0.69	2.81	0.64	9.85
Specific fuel consumption per unit of mass, l/shift/t	Q/G	6.5	6.3	3.07	5.9	9.23
Total fuel consumption per unit of performance, (l/shift)/(m^3/h)	Q/P	0.93	0.86	7.52	0.68	13.97
Dump speed, m/s	v	0.32	0.41	21.95	0.41	21.95
Cycle duration, s	t	63	57	9.52	57	9.52
Cost of soil development, UAH/m^3	S_{un}	17.86	17	4.81	16.74	6.22

A system is proposed that allows to adjust the temperature of the gas chamber, a hydro-pneumatic accumulator that allows to increase the pressure of the residual working fluid (**Fig. 11.6**).

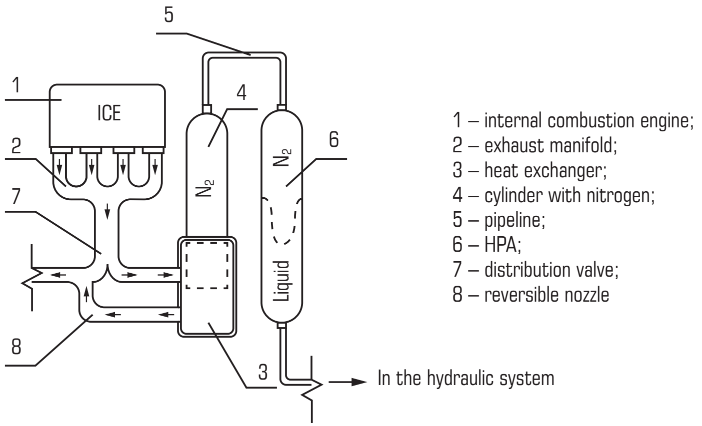


Fig. 11.6 Temperature regulator of the hydroaccumulating system
Source: author's development

The given scheme works as follows: at the moment when there is not enough pressure in the HPA to perform work operations, the distribution valve 7 blocks the flow of exhaust gases into the exhaust system and directs them to the heat exchanger 3, a cylinder with nitrogen gas (N_2) 4 is built into the heat exchanger, when the temperature rises in the cylinder 4, the gas expands and is fed through the pipeline 5 into the gas cavity of the HPA 6, thus the pressure in the working cavity of the HPA increases, when the nominal pressure in the working cavity of the HPA is reached, the regulating valve closes the flow of exhaust gases going to the heat exchanger and directs them to the exhaust pipe.

Experimental studies of this system showed an increase in the number of lifts of the working equipment on the accumulated energy (**Fig. 11.7**).

Thus, the prospects for the development of energy-efficient machines for earthworks can be presented as follows – **Fig. 11.8**.

That is, it is necessary to study the energy saturation of the working processes of machines and the phased consumption of power, taking into account the conditions in which they will work, which will allow to reduce the installed power of engines, the use of alternative energy sources and the creation of hybrid power plants [15, 16].

The conducted analysis determines the strategy of improving the machines for earthworks in the field of fuel efficiency and environmental friendliness. Hybrid power plants for such machines will be able to increase fuel efficiency by up to 30 % for newly designed machines and up to 20 % for those already in operation.

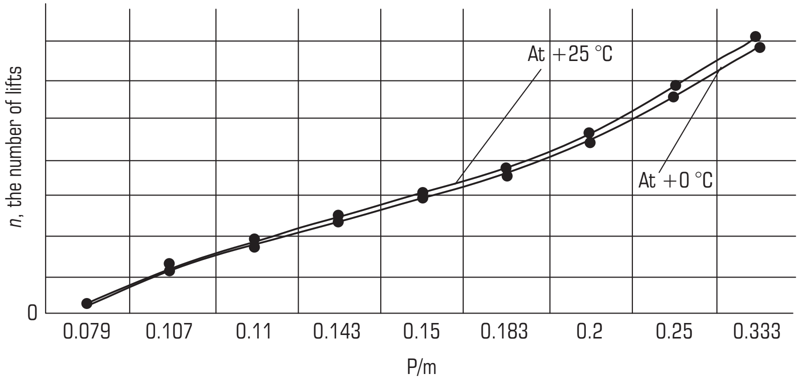


Fig. 11.7 Schedule dependencies quantity lifts working equipment from pressure charging and temperature surrounding environments of 0 °C and +25 °C
Source: author's development

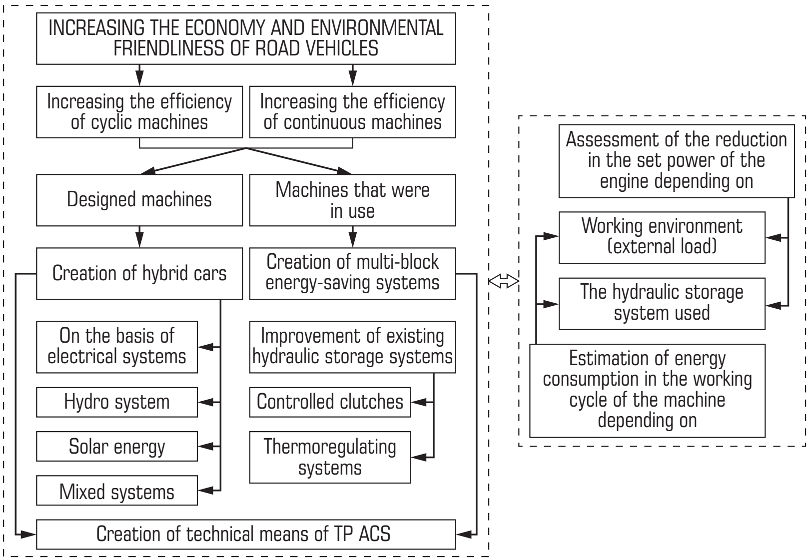


Fig. 11.8 Strategy for increasing the fuel efficiency of earthmoving machines
Source: author's development

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