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RESEARCH INTO PROMISING DIRECTIONS FOR IMPROVING TRACKED FORESTRY MACHINES

This review, based on an analysis of the current state of domestic forestry science and machine building, highlights the prospects for expanding the production and use of tracked forestry machines in logging and forest management operations. The advantages and disadvantages of wheeled and tracked platforms for forestry machinery are considered from the standpoint of operational and environmental performance, including their suitability for use in forests located on slopes. The aim of the study is to substantiate promising directions for the development of research in the field of improving tracked forestry machines and to justify their advantages over wheeled forestry machines. Therefore, a comparative analysis of wheeled and tracked forestry machines is both relevant and timely. This analysis demonstrates that a tracked undercarriage provides significant advantages over wheeled platforms and represents a promising direction for planning the future development of forestry machinery. It is shown that domestically produced tracked forestry machines have considerable potential for widespread application in forestry and logging operations. Compared with wheeled machines, these units are significantly more environmentally friendly and substantially cheaper to manufacture and operate. Numerous scientific publications allow an unambiguous conclusion that, without the use of additional technical means and technological solutions, the environmental compatibility of tracked propulsion systems (under otherwise equal conditions) is noticeably higher than that of wheeled systems. To reduce ground pressure on forest soils (by increasing the contact area with the running surface) and to improve passability, modern tracked forestry machines (harvesters based on excavator platforms) are equipped with widened track belts with a reduced number of grousers. Compared with modern wheeled forestry machines, tracked tractors have a significantly simpler transmission design and maintenance system, which is considerably less demanding in terms of maintenance quality and compliance with service intervals. Owing to their much simpler design, it is also possible to use components and assemblies from other similar types of transport machinery. The necessity for regulatory standardisation of the impact of forestry machines on soil is justified by the following indicators: permissible ground pressure; rut depth formed; and the degree of soil compaction.

Keywords: *forest management operations, wheeled forestry machines, tracked forestry machines, propulsion systems, efficiency, impact on forest soils, rut depth.*

***Introduction*.** The main objective of this study is to substantiate the prospects for further research aimed at improving tracked forestry machines.

The need for this research arises from the fact that, as a result of the almost complete destruction of the domestic forestry machinery manufacturing sector, which was traditionally based on tracked tractors, logging enterprises have shifted to imported wheeled forestry machines. Consequently, the dominance of imported wheeled tractors in timber harvesting operations has led to the formation of a widespread perception regarding the lack of prospects for tracked forestry machines.

In this context, the issue of the urgent revival of domestic forestry machinery manufacturing based on tracked tractors has become highly relevant. Therefore, conducting a comparative analysis of wheeled and tracked forestry machines is both expedient and timely. Such an analysis demonstrates that tracked undercarriages offer significant advantages over wheeled machines and represent a promising direction for planning the future development of forestry machinery [1].

In Europe, timber harvesting and forest management are combined under the unified term “Forestry” [2,3], within which forest users carry out the full range of timber harvesting and silvicultural operations, comprising four main stages: harvesting (felling) operations; timber transportation; forest landing operations, which serve as an intermediate stage between timber harvesting and wood processing [4,5].

It is also appropriate to highlight several important aspects.

First, the same machines are quite often employed at forest industry enterprises to perform harvesting, reforestation, and other silvicultural operations [6,7]. Based on the principle of modular system design, power and transport modules can be used across different operational stages [8].

Such multifunctional use of base forestry machines is largely facilitated by the seasonal nature of timber harvesting, reforestation, and other forestry operations [9,10]. For obvious reasons, reforestation and many other (though not all) silvicultural activities are carried out during the warm season, whereas timber harvesting-especially in forest areas with difficult soil and ground conditions – is preferably performed in winter, when the soil is frozen [11,12].

Among forestry machines, a distinct class of timber harvesting machines is identified [13].

This class includes machines structurally designed for tree felling and, as a rule, for performing a number of subsequent operations, namely:

- felling machines;
- felling-and-bunching machines;
- felling-and-skidding machines;
- felling-and-delimbing machines;
- felling–delimbing–cross-cutting machines (harvesters);
- felling–delimbing–cross-cutting–skidding machines (harwarders and forwarders);
- felling–skidding–processing machines [14-15].

That is, timber harvesting machines are defined as forestry machines that are primarily capable of felling trees. This classification is обусловлено, first, by the fact that tree felling is the initial operation in all technological processes of harvesting operations, and second, by the fact that in the vast majority of cases these machines are highly specialised and are not employed in other harvesting, reforestation, or silvicultural operations.

In addition to timber harvesting machines, the most highly specialised forestry machines also include loaders and processors (delimbing and cross-cutting machines used in the Canadian cut-to-length harvesting system) [16]. The most versatile in terms of application are skidding machines [17,18].

Results and Discussion. The main features of the division of forest machines.

It is well known that any forestry machine consists of a base chassis equipped with specific technological equipment intended to perform various technological operations [19]. As noted earlier, forestry machines may be classified according to the versatility of their application in harvesting, reforestation, or other silvicultural operations into highly specialised and versatile machines. However, this classification is rather conventional.

In the scientific literature, forestry machines are commonly classified according to the following criteria.

By type of propulsion system. According to this design criterion, forestry machines are traditionally classified into tracked and wheeled machines. In addition to these two classical variants, walking machines (Fig. 1a), developed by the Finnish company Timberjack, are also known. A less widespread, yet practically encountered, solution involves the partial use of tracked propulsion combined with wheels, namely semi-tracked machines (Fig. 1b).

Furthermore, a widely adopted practice in logging operations involves equipping wheeled forestry machines with wheel-mounted track systems of various designs (Fig. 2) in order to improve cross-country mobility; in such configurations, these machines are often referred to as wheel–track machines [20,21]..

a) b)

Fig 1. General view of forestry machines

Note: a) Harvester with walking propeller, Timberjack company, б) Forwarder on a half-track

Wheel-mounted tracks ECO-Wheel	Wheel-mounted tracks ECO-Track	Wheel-mounted tracks OF	Wheel-mounted tracks Combi-Track	Wheel-mounted tracks Baltic

Fig. 2. Olofsfors wheeled tracks

Wheel-mounted track type ECO-Wheel features a large contact area, provides satisfactory traction, improves machine stability, enhances cross-country mobility, and protects tyres from lateral cuts.

Wheel-mounted track type ECO-Track is one of the most versatile track types. It is suitable for most machine categories and provides satisfactory traction on soil and ground surfaces.

Wheel-mounted track type OF is designed for steep, rocky terrain. These tracks exhibit enhanced self-cleaning capability. Wheel-mounted track type Combi-Track is intended to improve machine mobility in hard-to-access areas. They provide satisfactory traction of the running gear on relatively viscous and soft soils.

Wheel-mounted track type Baltic is designed for soft soils. These tracks protect the soil from damage.

By type of technological operations performed. The previous section of this study has already identified various types of timber harvesting machines, as well as loaders, processors, skidding tractors, mulchers, rotovators, tree-planting machines, slash residue collectors, machines for soil preparation on clear-cuts and burned areas, and forest firefighting tractors [22]. In essence, this represents the complete core set of forestry machines, which may either be highly specialised or configured according to a modular design principle.

By the orientation of the service area relative to the direction of machine travel. Initially, this classification criterion was applied primarily to timber harvesting machines. However, with the development of forestry engineering and the increasing number and variety of machines configured on a modular basis, this criterion has subsequently been extended to all categories of forestry machines [23].

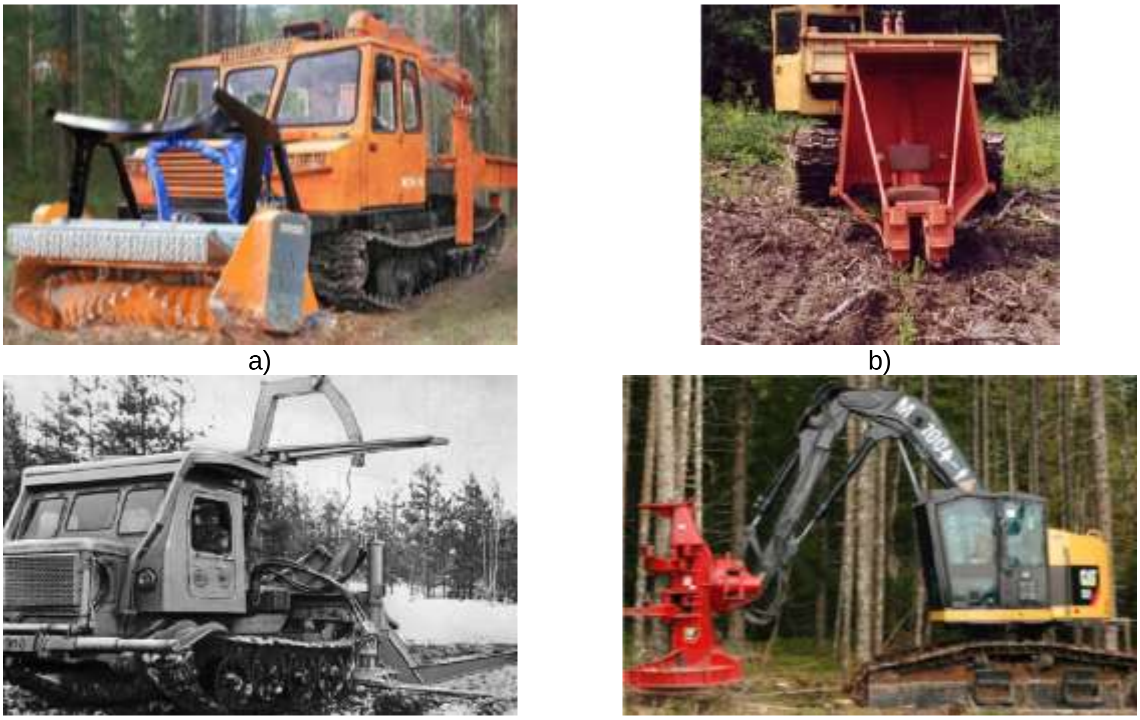
According to this criterion, forestry machines are classified as follows:

- Frontal machines, in which the technological equipment interacts with the work object in front of the machine or at the rear (Fig. 3a);

- Side-mounted machines, in which the technological equipment operates on the work object from one or both sides of the machine (Fig. 3b);

- Swing-type (fully rotating) machines, in which the technological equipment operates on the work object from the sides and the front of the machine, and in some cases also from the rear (Fig. 3c).

It should be noted that many fully rotating forestry machines are mounted on tracked excavator chassis [24].



a) b) c) d)

Fig 3. General view of forestry machines

Note: a), b) push-type forest machines, c) flanking forest machines, d) four-wheel drive forest machines

By the width of the treated forest strip. Like the previous criterion, this classification attribute was initially characteristic of timber harvesting machines but was subsequently adopted in the specialised literature with respect to other forestry machines.

According to the terminology and definitions of timber harvesting operations, a strip is defined as a part of a cutting area processed by a feller or a timber harvesting machine in a single pass [25].

If the technological equipment is rigidly mounted on the machine frame, the forestry machine is required to approach each work object individually (i.e. each location where a discrete operation is performed). In this case, the treated strip is narrow, and such machines are conventionally referred to as narrow-working-width machines.

If, however, the technological equipment is mounted on a hydraulic manipulator, which allows the working reach to be significantly increased and thereby substantially enlarges the area processed from a single operating position, the treated strip becomes wide. Such machines are conventionally referred to as wide-working-width machines.

Thus, the external distinguishing feature between narrow- and wide-working-width machines is the presence or absence of a hydraulic manipulator.

Narrow-working-width forestry machines are shown in Figure 3a, b, c whereas wide-working-width machines are shown in Figure 3d.

By affiliation with the type of work (group of technological processes). Under current conditions, this classification is rather conditional, since, as demonstrated above, some machines intended for timber harvesting operations can be converted into machines for reforestation and other silvicultural tasks without significant labour input. At the same time, certain machines cannot be adapted for other operations.

In this context, in our opinion, it is more appropriate to adopt a classification based on the following principle [26]:

- highly specialised machines for timber harvesting operations (for example, processors);
- highly specialised machines for silvicultural operations (for example, tracked forest firefighting tractors);
- universal machines.

Loaders represent a more specialised category of machinery that completes the technological processes of timber harvesting operations. Swing loaders are intended exclusively for whole-tree (stem) harvesting, whereas manipulator-based (fully rotating) loaders can be used for both whole-tree and cut-to-length harvesting systems. In the case of whole-tree harvesting, such machines are equipped with specialised gripping devices, while during the handling of assortments they are fitted with conventional grapple attachments.

The division of forestry machines into highly specialised and universal categories fully applies to reforestation and other silvicultural operations as well [27].

It is well known that any technical solution has its own advantages and disadvantages; historically, domestic forestry and forest-management tractors were predominantly crawler-type machines. From the standpoint of efficient operation, a key recommendation was that, depending on engine power, such machines should be used in stands with an average stem volume of 0.4 m³ or greater.

Analysis of the dynamics of rutting

The running gear of specialised crawler forest skidders, characterised by a highly raised front idler and a rear drive sprocket of the track system, can readily overcome site-specific obstacles encountered on logging areas (hummocks, stumps, fallen stems, stones) that are not typical of agricultural land or construction sites. By contrast, the crawler undercarriage of a conventional construction machine performs poorly when negotiating forest obstacles.

Figure 4 clearly illustrates the differences between the running gear of forestry and construction tractors.

Fig 4. Visual comparison of the chassis of forestry and construction tractors

The primary advantage of a crawler propulsion system over a wheeled tractor is traditionally considered to be its superior cross-country mobility. For machines of equal mass, a crawler system provides a significantly larger contact area with the surface of the logging site, resulting in lower ground pressure and higher tractive force, assuming equal engine power and transmission efficiency [28,29].

Owing to the reduced pressure exerted on forest soils, crawler-based forestry machines, all other conditions being equal, demonstrate better environmental compatibility with the forest ecosystem [30].. Considering that soils of categories III and IV, i.e. soils with low bearing capacity, predominate on more than half of the forest fund lands, as well as taking into account the gradual yet clearly observable warming of the climate, tracked forestry machines are quite often preferable to wheeled ones.

In accordance with regulatory obligations, forest users are required to undertake reforestation activities. The cost of reforestation works is included in the overall cost of timber harvesting products, and the more soil-friendly impact of tracked forestry machines compared with wheeled machines (under otherwise equal conditions) contributes to an increase in both the environmental and economic efficiency of timber harvesting and forest regeneration [31].

Undoubtedly, under unfavourable soil and ground conditions or deep snow cover, wheeled forestry machines may be equipped with the above-mentioned wheel-mounted tracks; however, their acquisition requires additional-and substantial-financial expenditure. Moreover, for different operating conditions, each wheeled forestry machine requires the purchase of several different sets of such wheel-mounted tracks. For example, for a single wheeled forestry machine, a minimally reasonable set comprising swamp tracks and snow tracks must be acquired [32], which entails significant additional costs.

Without wheel-mounted tracks, heavy wheeled forestry machines cause considerable damage to the forest environment, primarily through excessive soil compaction. This leads to reduced soil aeration, deterioration of the hydrological regime, and the formation of deep ruts, which subsequently often become focal points for the development of water erosion and, in some cases, wind erosion.

Figure 5 illustrates a deep rut left by a wheeled forestry machine after a single pass. Considering that skidding systems are among the most heavily loaded forestry machines and that dozens of passes are required along a single skid trail to extract timber harvested on a cutting area, it becomes evident that the operation of wheeled forestry machines under such conditions results in almost irreparable damage to the forest environment.

Moreover, this damage is prolonged over a very long period. In addition to a long-term reduction in the ecological functions of forest stands, the duration of reforestation is significantly increased and its quality is reduced, both in terms of growth increment and the commercial value of the subsequent forest succession [33].

Fig. 5. A deep track left by a wheeled forest machine in one pass

Numerous scientific publications allow an unambiguous conclusion to be drawn that, without the use of additional technical means and technological solutions, the environmental compatibility of tracked propulsion systems (under otherwise equal conditions) is significantly higher than that of wheeled systems [34].

It should be noted that the root system of trees consists of two main types of roots: anchoring roots**,** which ensure the fixation of the tree in the soil, acting in a manner analogous to a cantilever beam; and absorbing roots, which are responsible for the uptake of water-dissolved mineral nutrients from the soil.

During selective logging operations, damage to or suppression of absorbing roots-primarily as a result of compaction of the surrounding soil – has an extremely negative effect on the subsequent growth of trees left for further development, as well as on undergrowth and young stands. At the same time, absorbing roots are predominantly located in the upper soil layer [35,36], the thickness of which is extremely limited [25].

The presented load diagrams (Figs. 6–7) for wheeled and tracked forestry machines clearly confirm the higher environmental compatibility of tracked propulsion systems with the forest environment.

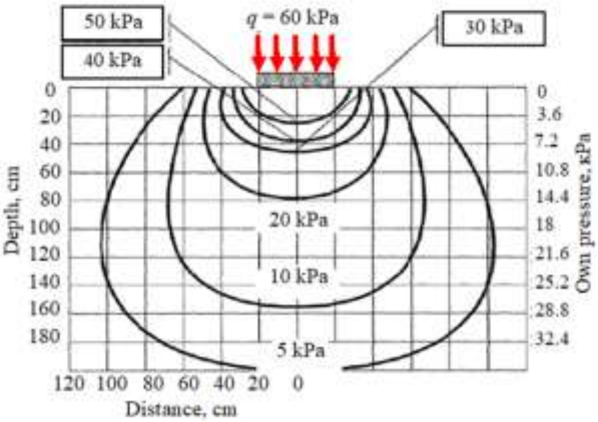


Fig. 6. Diagram of additional stresses in an ideal soil and its own pressure at a density of 1.8 g/cm3

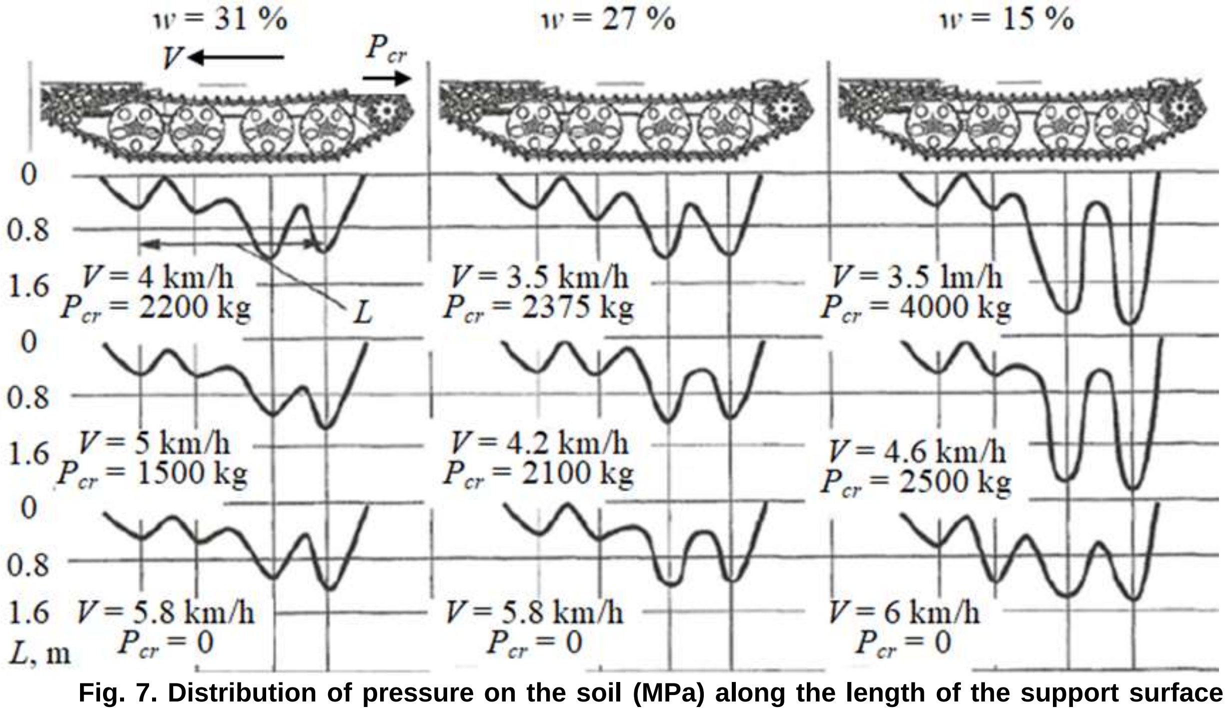


Fig. 7. Distribution of pressure on the soil (MPa) along the length of the support surface depending on humidity, speed and traction of the crawler tractor

It should also be taken into account that soil compaction occurs not only directly beneath the running gear but also at a certain lateral distance from the skid trail or technological corridor. The dynamics of rut formation may vary considerably and differ substantially depending on the presence of numerous objective and subjective factors [37, 38].

On firm soils, during the initial passes the running gear compresses the upper soil layer, after which the rut depth increases only insignificantly; the resulting dynamics resemble a logarithmic pattern of change.

On weak soils, the rutting process does not stabilise, and the rut depth continues to increase until the trafficability of the skid trail is exhausted, that is, until the rut depth becomes equal to the ground clearance of the forestry machine. The intensity of this process may vary.

Under repeated passes and high contact pressure on the soil-conditions typical of wheeled machines – the bearing capacity of the firm underlying soil layer may eventually be exceeded. This leads to a sharp increase in rut depth, after which the machine may begin to "sink" (Fig. 8).

Fig. 8. «Flooding» of the wheel forwarder under poor soil conditions

The operational case shown in Fig. 8 is far from uncommon during the operation of wheeled forestry machines, yet it is relatively rare for tracked machines. Following such "flooding" of a wheeled tractor, it must be transported to a heated maintenance bay, washed, and have seals, cuffs, oil seals, and related components cleaned and serviced [39]. In contrast, for a tracked tractor, even if it encounters a similar adverse situation, such an extensive set of maintenance operations is generally not required.

The presented dependences of the dynamics of rutting (Fig. 9) of wheeled and tracked forestry machines clearly confirm the advantages of using tracked engines on logging machines.

As can be seen from Fig. 9, a heavy wheeled forestry tractor forms a rut much more intensively (under equal operating conditions) than tracked tractors.

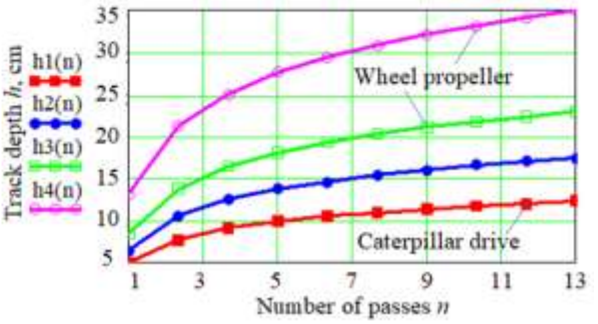


Fig. 9. Dynamics of track formation of tracked and wheeled skidding tractors depending on the number of passes

Features of the dynamic pressure of crawler motors on the ground

In order to reduce contact pressure on forest soils (by increasing the contact area with the running surface) and to improve trafficability, modern tracked forest harvesting machines (excavator-based harvesters) are equipped with widened track shoes featuring a reduced number of grousers [40].

Compared with modern wheeled forestry machines, tracked tractors have a significantly simpler transmission design and are substantially less demanding in terms of maintenance quality and adherence to service intervals, which, under the conditions of forestry enterprises-especially small-scale ones – is often difficult to ensure [41].

When considering the cost of wheeled and tracked machines as a whole, and bearing in mind that logging enterprises are among the least financially secure within the forestry sector, it is worth noting that, all else being equal, the purchase cost of a wheeled forestry machine is approximately 40–50% higher than that of a tracked machine of the same traction class and intended application [42].

At the same time, tracked forestry machines also have a number of significant disadvantages compared with wheeled machines. First and foremost, these include increased fuel consumption (up to 40% under otherwise identical conditions) and substantially lower travel speeds (under favourable soil conditions and shallow snow cover), which considerably reduce productivity, especially in transport operations, primarily skidding [43]. Under conditions of a highly fragmented harvesting area, forestry machine systems must frequently be transported over long distances (from one cutting area to another, or between sites designated for forest regeneration or other silvicultural operations) (Assessing Rutting, 2024).

Wheeled forestry machines can, in principle, relocate under their own power, whereas tracked machines must be transported exclusively on low-bed trailers, requiring additional equipment such as prime movers. Moreover, not all forest roads are suitable for trailer access. Self-propelled movement of tracked machines on roads may lead to damage of the road surface, particularly paved roads. Consequently, unlike wheeled machines, tracked machines are not permitted to travel under their own power on public roads. It should also be noted, however, that the hydraulic transmission of wheeled forestry machines is not designed for long-distance travel, as it tends to overheat; an exception is the Ponsse Bison forwarder, which is structurally intended for long-distance relocation [44].

Tracked running gear in forestry machines is subjected to very high dynamic (impact) loads during motion, especially in skidding tractors, which must perform empty runs to the felling site and loaded runs to the landing at the highest possible speeds. When encountering and passing over obstacles, the track alternately tightens and slackens, while the connecting pins strike their seating surfaces, sometimes acting like a pump that draws liquid mud into the joints.

This results in relatively rapid wear. A major problem in modern forest machine manufacturing is the very low quality of steel used for the production of tracks for forestry machines [45]. Based on the above definition of “forestry and forest harvesting machines”, it is therefore necessary to consider the types of tracks used on such machines.

It should be noted that forestry machines of different functional purposes perform different numbers of movements within a cutting area, which affects not only the design of the technological equipment and running gear, but even the fuel tank capacity. For example, the fuel tank capacity of a harvester is significantly greater than that of a skidding tractor [46].

This is due to the fact that harvesting machines must fell trees while moving between technological working positions. A large fuel tank is required in order to minimise the frequency of travel to the landing (or loading point) for refuelling. In contrast, skidding tractors regularly deliver timber to the landing (loading point), making it easier for them to refuel more frequently rather than carrying a large volume of fuel, which would increase the tractor tare ratio and lead to associated negative consequences.

In principle, forestry machines may be divided into transport and technological machines. Transport forestry machines-primarily skidding tractors and, to a lesser extent, loaders-perform a large number of movements (transport work) compared with technological machines. Tracked forest harvesting machines, such as harvesters, as well as forest processors and loaders, are commonly based on construction-type manipulator machines, namely excavators [47].

As noted above, skidding tractors should preferably have a lower mass in order to reduce the specific energy consumption associated with the primary transportation of harvested timber. Accordingly, tracked skidding tractors are equipped with the simplest and lightest track systems featuring single-rib engagement, in which the successive joints consist of track links and pins manufactured as castings. These systems are assembled with minimal accuracy requirements and do not include seals or lubrication within the joints. Such tracks are considerably cheaper than those used on construction machinery, but their service life is relatively short. Owing to the aforementioned decline in steel quality, their operational lifespan is reduced even further.

Tracks used on construction tractors consist of a chain with sealed links incorporating lubricated joints, to which track shoes are bolted. These tracks are relatively expensive but have a long service life. Due to lubrication, the wear rate is significantly reduced – by up to 20%.

According to joint lubrication methods, tracks are also classified as follows: dry (open metal joint); sealed (lubricant is introduced into the joint for the entire service life); liquid-lubricated (seals ensure joint tightness to retain lubricant); rubber–metal joint (a rubber bushing is installed between the pin and the track link); needle-bearing joint.

When metal tracks are installed on a tractor, the drive wheels take the form of sprockets, the teeth of which engage with the track chain. When rubber–metal tracks are installed, they typically have a smooth contact surface interacting with a smooth drive wheel, with torque transmission occurring through friction.

A distinct set of operating conditions for forestry machines arises under snow cover, which in certain cases creates working conditions as challenging as weak soils during the warm season. This often necessitates the use of harvesting layouts with increased density of skid trails and technological corridors. On the one hand, snow cover conceals individual obstacles such as logs, stumps, hummocks, stones, and similar objects. On the other hand, it increases the coefficient of motion resistance. During turning manoeuvres of tracked machines, snow tends to pack into the tracks, and it should be borne in mind that a tracked skidding tractor spends the majority of its travel time operating in a turning mode.

Conclusions. The results of the above analysis of the current situation in modern forest machine manufacturing, as well as in the supply of spare parts and consumables for forestry machines, indicate that forestry machines based on tracked chassis have very strong prospects for widespread application in both forestry management and forest harvesting operations. Compared with wheeled machines, these machines are significantly more environmentally compatible, less expensive to manufacture and operate, and machinery plants possess extensive experience in producing such equipment.

The depth of the track formed by a tracked vehicle with a number of passes equal to five is almost two times less than the depth of the track formed by wheeled vehicles with an adequate number of passes and mass of the vehicles.

Owing to their substantially simpler design, there are no fundamental difficulties in achieving 100% localisation of components within the country.

At the same time, a specific but significant challenge in the production of forestry machines in general (and tracked machines in particular) is associated with the sharply deteriorated quality of metals supplied by metallurgical plants.

The results obtained provide the opportunity for further research aimed at developing promising areas of application and ways to increase the technological efficiency of logging operations.

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ДОСЛІДЖЕННЯ ПЕРСПЕКТИВНИХ НАПРЯМКІВ УДОСКОНАЛЕННЯ ГУСЕНИЧНИХ ЛІСОВИХ МАШИН

Цей огляд, заснований на аналізі поточної ситуації у вітчизняній лісовій науці та машинобудуванні, висвітлює перспективи розширення виробництва та використання гусеничних лісозаготівельних машин у лісозаготівельних та лісогосподарських роботах. Розглядаються переваги та недоліки колісних та гусеничних платформ для лісозаготівельних машин з точки зору експлуатаційних та екологічних характеристик, включаючи їхню придатність для використання в лісах на схилах. Мета роботи – обґрунтування перспективних напрямків розвитку досліджень в галузі удосконалення гусеничних лісових машин і їх переваг використання порівняно з колісними лісовими машинами. Тому, доцільним та своєчасним є проведення порівняльного аналізу колісних та гусеничних лісових машин, який показує, що гусенична база для лісових машин має свої суттєві переваги щодо колісних машин та є перспективним напрямом при плануванні розвитку лісових машин. Показано, що вітчизняні лісозаготівельні машини на гусеничних шасі мають значний потенціал для широкого застосування в лісогосподарських та лісозаготівельних роботах. У порівнянні з колісними машинами, ці агрегати значно екологічніші і суттєво дешевші у виробництві та експлуатації. Численні наукові публікації дозволяють зробити однозначний висновок про те, що без використання додаткових технічних засобів і технологічних рішень екологічна сумісність гусеничного рушія (за інших рівних умов) помітно вища, порівняно з колісним. Для зниження тиску на ґрунтоґрунти лісосік (збільшення площі контакту з їздовою поверхнею), підвищення прохідності на сучасні гусеничні лісозаготівельні машини (харвестери на базі екскаваторів) встановлюють розширену гусеничну стрічку із зменшеним числом ґрунтозачепів. Порівняно з сучасними колісними лісовими машинами у гусеничних тракторів значно простіше влаштування та обслуговування трансмісії, яке помітно менш вимогливе до якості та дотримання термінів технічного обслуговування. Завдяки значно простішій конструкції, можливе використання комплектуючих та вузлів від інших аналогічних типів транспортної техніки. Необхідність нормативної стандартизації впливу лісозаготівельних машин на ґрунт обґрунтована такими показниками: допустимий тиск на ґрунт; глибина колії, що утворюється; ступінь ущільнення ґрунту.

Ключові слова: *лісогосподарські роботи; колісні лісові машини; гусеничні лісові машини; рушії; ефективність; вплив на ґрунтоґрунти; глибина колії.*

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