# Requirements for a chainsaw operator's exoskeleton

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**Abstract.** Despite the mechanisation of the forest industry, the profession of a tree feller is still in demand. A tree feller with chainsaw works under great physical strain on all muscle groups. A distinctive feature of the job is the need to constantly change working postures and the need to hold a fairly heavy petrol-powered chainsaw in your outstretched arms. Facilitating the working conditions of the tree feller by reducing his or her physical fatigue is an urgent task. In order to achieve the purpose of this work, it was necessary to investigate the working conditions at a tree feller's workplace, to study the exoskeleton designs used in different branches of industry, and to formulate the requirements for a chainsaw operator's exoskeleton design. To achieve the goal and solve the designated tasks, the use of patent information search methods, among scientific and technical literature, comparison, functional-structural-technological analysis, allowed one to establish the currently achieved technical level of exoskeletons and trends in their development. Thanks to the use of the brainstorming method in addition to the aforementioned methods, it was possible to achieve the final result of the work, which consists in the formulation of requirements for an exoskeleton for a chainsaw operator. Key words: exoskeleton, chainsaw operator, logging, tree felling with chainsaw

## 1 Introduction

The share of logging technologies with the use of gasoline-powered tools is more than 50% of the total logging in the Russian Federation [1]. Even in Northwest Russia, where fully machine-assisted assortment technology prevails, it is often impossible to handle individual large trees without a chainsaw; using of tree fellers are also effective on steep slopes, wetlands, and windfalls, and, in addition, the involvement of tree fellers can be more effective on low-volume logging, selective felling, and in forestry maintenance.

The job functions of a tree feller include preparatory work at the felling site before falling, felling and splitting trees with chainsaws, sawing stumps flush with the ground, preparing raw wood for skidding, and maintaining and repairing the chainsaw used. According to the same standard, the work activities of a tree feller, in addition to those involving the use of a petrol-powered saw, also include chopping firewood on harvesting areas, chopping down tree limbs and tops by hand with an axe, collecting chopped limbs and tops, cut undergrowth and

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undergrowth in piles and windrows, hoeing stumps after grubbing, stacking split logs and firewood in bundles.

It is known that harmful and dangerous work factors and working conditions for tree fellers include:

- environmental conditions - frost, heat, wind, precipitation (rain, snow, hail), mosquitoes, etc;
- increased vibration level caused by gasoline-powered tools;
- excessive operating noise caused by the gasoline-powered tool;
- unprotected moving saw chain with sharp edges;
- pieces of wood thrown off at high speed by the teeth of the saw chain;
- excessive exhaust fumes in the work area on the side of the power tool;
- heated surfaces of the chainsaw engine;
- exposure to biological factors (tick-borne encephalitis);
- potential for injuries caused by slips, trips and falls;
- physical overloads including: static loads due to the weight of the tool being held in the air (gasoline-powered saw) and dynamic loads due to the weight of the load being lifted and moved (cut branches, limbs, tree tops, chopping firewood);
-stereotypical working movements when choosing a comfortable position for technological operations (bending and twisting the body, squatting, working with a weight (petrol-powered saw) held on outstretched arms, moving over difficult terrain, etc.).

This puts a lot of physical strain on the legs, back muscles and arm muscles. The feller constantly has to bend forward, sideways, crouch down to choose a comfortable position for felling, delimbing, and also has to use physical strength to gather cut branches and tops into piles, and to cut firewood.

In order to prevent or reduce the negative impact of harmful and dangerous factors on the tree fellers, specially developed methods of protection are used, which are divided into technological and technical ones. Technological methods include, for example, regulating the duration of the working shift, rationing of breaks. Technical methods are more effective and are divided into two groups: reduction of the degree of harmful effects at the source of its excitation and protection against their effects on the paths of propagation. The methods of the first of these two groups are implemented by the manufacturers of technical devices, and the users of equipment cannot influence them, e.g. the vibration level on the handle of a petrol-powered saw is reduced by using damping elements, the noise level is reduced by using a silencer, the directional emission of sawdust is provided, etc. However, users may improve their working conditions by employing the second group of techniques, namely the use of personal protective equipment. These include:

- anti-vibration gloves or mittens - to protect against vibration;
- headphones or earplugs to protect against excessive noise;
- safety shoes, helmets, face shield, saw-through protection suit - to protect against injuries;
- special thermo-regulating, waterproof clothing - to ensure a comfortable working temperature;
- colourful inserts in clothing - for visibility on the felling site.

An analysis of personal protective equipment for tree fellers shows that currently they do not use any means to reduce physical strain.

Bances E. et. all in work [2] note that nowadays exoskeletons are increasingly widely used to create comfortable working conditions, ensuring optimal human performance and preservation of health when performing physically demanding, monotonous production operations in various industries, including woodworking. O'Sullivan L., Nugent R., J. van der Vorm in work [3] note that there is no certain standard for exoskeletons.

The development of an exoskeleton for tree fellers, taking into account the peculiarities of their work activities, seems to be an urgent task for the timber industry.

## 2 Literature Review

Zhu Z., Dutta A., Dai F. in [4] provided an overview of known exoskeleton designs, analyzed the potential of their use for various tasks. It is known that exoskeletons can be classified according to various attributes, among which the main ones are: the need for an external power source; the presence of servo drives and their operating principle; the field of application based on the number of functions performed; the degree of muscular activity of the user; the price category.

A distinction is made between active and passive exoskeletons.

Active exoskeletons use in their construction devices that convert electric energy from an external power source into mechanical one, driving in motion structural elements fixed on the human body. Active exoskeletons are able to compensate for the non-motor functions of the body, which has made them widely used in medicine. However, these exoskeletons have not been widely used in industry, due to their large size, weight and high cost.

Anam K., Al-Jumaily A.A. in [5] and Ivanov D.V. et. all in [6] pointed out that the characteristics of an active exoskeleton include such indicators as operating stability, operational safety, service life, design weight, power consumption level, autonomous operation time, radius of autonomous movement.

Passive exoskeletons are lightweight designs that have no active drive parts, and use the residual force of human muscles as their energy source. Because of their low weight and ease of use, passive exoskeletons have found use in a variety of industries to enhance a person's physical capabilities and protect them from injury.

Exoskeletons are available for the upper limbs, lower limbs, back and suit exoskeletons. The exoskeleton suit is designed to increase the strength and performance of the entire body and provide protection from external influences. It is used to increase the user's ability to work. It can be active or passive. Awad L.N. in [7] described an exoskeleton suit for walking and running, which looks like ordinary sports shorts with a set of straps and an electronic unit. The weight of the device does not exceed five kilograms. The solution uses artificial intelligence, which analyses a user's movements and adapts the behaviour of the exoskeleton's mechanisms to suit them.

Bougrinat Y., Achiche S., Raison M. [8] describe the design of an active exoskeleton for ankle joint with autonomous power supply. They noted that the use of this device reduced the activity of the muscles involved in walking by about 40%.

Lovrenovic Z. and Doumit M. [9] described the design of a passive walking aid exoskeleton based on spring action. The design allows increasing the lifting force from 9.41% to 26.18% of the human body weight, depending on one of five spring stiffness levels.

Osipov A. in work [10] gives an overview of exoskeletons for firemen and the results of a comparative analysis of different exoskeleton models from the perspective of their use in professional fireman activity.

Borisov A.V. et. all in [11] present the results of simulating the motion of an agricultural worker using a passive exoskeleton with torsion and compression springs when performing work with increased physical exertion.

Bai S. et. all in [12] described the design of an exoskeleton suit consisting of separate modular flexible exoskeletons for lower and upper body parts, which can be combined into a common system. Such an exoskeleton has 27 degrees of freedom, of which 17 are passive and 10 are active.

Considering the information given by Elprama S.A., Vanderborght B., Jacobs A. in [13], the main requirements for an industrial exoskeleton suit include:

- An anthropomorphic structure, i.e. the exoskeleton design should take into account the location of the user's muscles, their structure and peculiarities of functioning, and the exoskeleton attachment to the user's body should consider the physiological features of the person and should not impair blood circulation, breathing, etc.;

- Low weight, which has a positive effect on the controllability of the exoskeleton, as high weight increases inertia effects and negatively affects reaction speed to control commands. High weight also increases the risk of injury from falls or other accidents;

- High strength and reliability - in the event of failure of exoskeleton components, all external loads will be sharply transferred to the user, which could lead to injury;

- availability of adjustments to user parameters, which should be intuitive, comfortable and have protection against accidental actuation;

- the ability to quickly readjust to suit different tasks. This will make the exoskeleton multifunctional and suitable for various production tasks;

- ability to dismount quickly in the event of an emergency;

- Autonomy of operation, which means independence from external power sources and control signals;

- protection against dust, moisture, shock and vibrations.

J. Van der Vorm, Nugent R., O'Sullivan L. in [14] consider issues related to the prospects of using exoskeletons in the repair and maintenance of road transport. The authors note that the use of exoskeletons in vehicle repair and maintenance is possible in physically demanding vehicle assembly and disassembly operations and contributes to improving working conditions, increasing labor productivity and safety, improving the company's image.

Challenges associated with the complexity of creating an exoskeleton include finding a power source, selecting a frame design, and developing a control system. The energy source could be a single-use or rechargeable battery. A non-recurrent battery requires complete replacement once discharged, while a rechargeable battery requires continuous recharging. A petrol engine can be used as a power source, but it is bulky, requires heat dissipation and an electric generator. The frame can be made of different materials. Steel frame is too heavy. Aluminium frames are lightweight, but not suitable for too heavy loads. Titanium and carbon frames are too expensive. The challenge of designing a control system is that you can't design for the same reaction speed of different users, and the control system must be able to neutralise excessive and unwanted manipulation. Sensors that scan telemetry data for the operator could malfunction and cause injury to the user.

Exoskeletons, depending on their purpose, e.g. military use, medical use for rehabilitation and habilitation, industrial use, rescue use, must meet different requirements and, as a consequence, be designed differently.

## 3 Materials and Methods

Object of the study: the working conditions of a forestry worker.

Subject of the study: the personal protective equipment of the wood slicer.

Objective: to improve the working conditions of the wood slicer by reducing his physical fatigue.

Objectives:

1. to study the working conditions of the wood slicer and the physical stress experienced by him;

2. to investigate exoskeleton designs known from the state of the art and their applications;

3. to propose a concept of an exoskeleton for a forestry worker.

To achieve the goal and solve the tasks, the following methods were used:

- patent information search and analysis of scientific and technical literature;

- comparison method;
- method of functional-structural-technological analysis;
- a method of brainstorming.

## 4 Results and Discussion

The advantages of active exoskeletons in comparison with passive ones are: possibility of high speed of movement; multiple increase in strength and amplitude of user's movements; possibility of regulation of working parameters for a particular user; possibility of computerization with subsequent programming of movement parameters; possibility of use in case of residual muscle strength absence; repairability.

The disadvantages of active exoskeletons in comparison with passive ones are: need for external power supply, high cost, great weight, the need for protection from precipitation, difficulty in structural adaptation to anthropometric features of the body of a particular user, the need for maintenance, difficulty in putting on and taking off when using, in the construction there are rigid elements of the frame.

The advantages of passive exoskeletons in comparison to active ones are: no dependence on external power supply; low weight; high reliability due to the simple design, low cost of the device and its maintenance, there are both rigid and soft structures.

The disadvantages of passive exoskeletons in comparison with active ones are: impossibility of use in the absence of residual muscle strength, impossibility of programming, significantly lower ability to increase movement speed, muscle strength and amplitude of movements.

In industry, exoskeletons are mainly used to reduce the static load of workers. Exoskeletons are known to be used in heavy industry as protective equipment for workers. Passive exoskeletons are best suited for this purpose.

A comparative analysis of active and passive exoskeletons in the context of a tree fellers working environment led to the following requirements for a chainsaw operator's exoskeleton

- not to restrict the operator's movements. A feller has to change his position all the time, moving from tree to tree and vice versa. A typical harvesting posture is shown in Fig. 1;
- the machine must have as few protrusions as possible, and all components must form a perfect fit on the human body. As the operator moves through the forest and encounters obstacles in the form of deadwood, brushwood, deadwood, branches and limbs that protrude from the tree trunk at different heights - especially when limbing fallen trees - protruding or loose structural elements can cause the operator to get caught on obstacles, which can result in an injury hazard;
- due to difficult environmental conditions (high or low temperatures, rain, snow) the use of external power supply in an exoskeleton is undesirable;
- the presence of vibration effects from gasoline-powered tools transmitted to the forest machine operator makes it undesirable to use movable mechanical joints in the exoskeleton design due to their low durability in such conditions. At the same time the exoskeleton must not increase the amplitude of movements caused by vibration;
- Reducing the static and dynamic stresses on the windrower during stereotyped movements. The exoskeleton must reduce stress on the arms (wrist, elbow and shoulder joints), legs (knees, hips) and back muscles;
- low weight;
- should be easy to put on and take off;
- fit both on and underneath the chainsaw operator's protective suit;
- inconspicuous to the wearer;
- a long service life;

- high resistance to mechanical damage;
- low cost;
- easy maintenance.

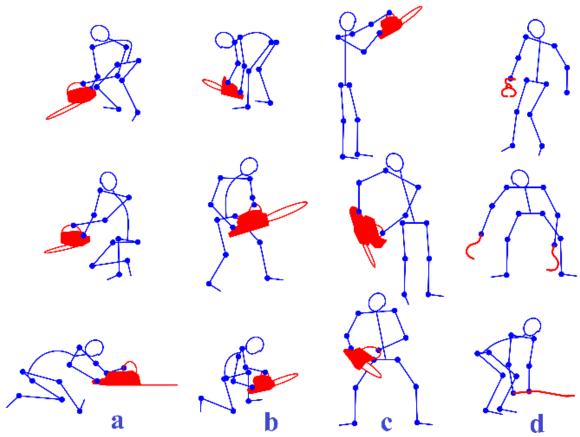


**Fig. 1.** Typical working postures with static and dynamic load: a - felling posture; b - bucking posture; c - delimbing posture; d - auxiliary harvesting posture

The design of a soft passive exoskeleton is more suited to the needs of the tree fellers working environment.

The exoskeleton can be made up of separate components for the upper limbs, lower limbs and back muscles - in this case the tree feller, depending on his/her well-being and physical condition, can complete this ammunition independently. The exoskeleton can also be combined with a protective suit for the chainsaw operator. In this case, the suit would need to be customised to suit the physiological and anthropometric conditions of the tree feller, which would inevitably increase the cost of the suit due to one-off production. In the case of mass production, an exoskeleton suit would need to be developed with the ability to adjust individual components to suit the needs of the individual user.

The use of individual components in an exoskeleton is preferable. This would make it more difficult to put on than a suit, but would allow for different stiffness and geometry of the elements in different areas, taking into account physiological and anthropometric features of a particular user. Also, as individual elements wear out, they can be easily replaced.

The stiffness and mobility of the exoskeleton elements must be selected taking into account the weight of the petrol-powered tool used by the tree feller in his work. It is known that considering the physiological possibilities of the operator's body the weight of gasoline-powered chainsaw in charged state must not exceed 12 kg. As the saws are improved, their weight decreases. The weight of the petrol-powered chainsaw depends on the operator's object of work, namely the diameter of the tree trunks to be cut. The larger the diameter of the tree, the longer the guide bar, the longer the chain and the higher the engine power required, which leads to heavier petrol-powered tools. This circumstance must be taken into account when selecting the power parameters of the exoskeleton.

In winter the temperatures on the forehead, hands and feet go down at the beginning of the day and then up again at the end of the day - the temperatures can fluctuate by up to several degrees. In summer and winter a logger wears clothes with different thermal insulation. This is something to consider when choosing the right material for a passive exoskeleton to ensure a good thermoregulation in the forest machine.

It is known that in the process of a tree fellers work the hand muscles' endurance to static forces is reduced by the end of the working day, and the reduction is much stronger in the right hand than in the left, which is explained by the higher load on the right hand, which is more loaded in the working process. This indicates the need for an exoskeleton with different strength characteristics of similar (left, right) individual elements, taking into account the force factors acting on each of them.

## 5 Conclusion

The use of an exoskeleton by a forestry worker will ease the working conditions of the tree feller, reduce stress on his body and thereby increase productivity and reduce fatigue. A reduction in fatigue, in turn, will contribute to higher concentration and, thus, lead to a reduction in injuries.

The development of a tree fellers exoskeleton presents a number of challenges because of the large number of muscles involved in working at a harvesting site, working with or without tools, working in confined spaces, especially when limbing fallen trees, working away from power sources, being outdoors under the influence of rainfall, daytime temperature fluctuations, etc.

An exoskeleton is not a substitute for the personal protective equipment that the tree feller is obliged to wear on the job. It must be used in addition to them. Using an exoskeleton will make it much easier for the tree feller to do his job.

Currently, there is an increase in the use of exoskeletons in various industries. Information search has shown that there is a lack of such technical solutions in the forest industry, in particular in relation to the profession of a tree feller.

The analysis of constructive and technological solutions made it possible to establish requirements for an exoskeleton, taking into account the characteristics of a tree feller's workplace, physiological, force loads on his body, and the nature of movement of each of the limbs.

It should be noted that among the challenges facing the development and implementation of exoskeletons in industry are:

- the large number of degrees of freedom of the human body;
- the speed of actuators needs to be synchronized with the speed of human muscles.

The results obtained can be used in analysing the existing designs of exoskeletons and choosing the most suitable one for the operator's workplace, as well as their further modification for specific natural-production conditions of use with regard to anthropometric, strength characteristics of the operator and mass and geometric characteristics of the tools used in his work.

At present, the authors are working on creating a system for monitoring the muscular activity and amplitude of movements of the tree feller's limbs in order to substantiate the necessary rigidity and elastic properties of the exoskeleton's structural elements, taking into account the individual loads on the individual muscles and joints of the chainsaw operator.

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