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# RELAZ Devices*

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*The biggest energy resource on our world is the sun. Its energy is conserved literally everywhere, for example on wind or in wood. In this paper, we deal with one of the less known sun energy form. This new alternative and renewable energy resource was called "mountain energy", because it is kept by trees growing in mountain ranges. The new energetic subsystem concept was designed to use this energy for empowering machines. Devices created in relation to this new conception was called "RELAZ devices" (Recuperative Cable Devices). Technical description of these hybrid devices is in the second focus part of this paper. RELAZ devices were initially designed for foresters working in mountain ranges. Principles used in RELAZ devices construction allows us to use them in working machines with combustion engines in common. RELAZ devices are hybrid devices. They are equipped with an internal combustion engine that only serves to charge a powerful energy battery. The charging process is carried out at the nominal speed of the internal combustion engine, which allows to reduce fuel consumption by 3-4 times. Therefore, RELAZ devices can be used profitably not only in mountainous areas, but also on the plain. The optimal mode of operation of RELAZ devices , which has a wider range than the classic machines, has been found. The specific energy of the RELAZ devices are less than that of the classic machines. It has been found that the use of a RELAZ cable car on the W30 forest cable car produced in Switzerland can save 780 litres per year of diesel fuel, which is 64 % of the savings. The results confirm the prospects and competitiveness of the RELAZ devices.*

**Keywords:** mountain energy, RELAZ devices, energy recuperation, forestry mechanisation devices, forestry cable yarders.

## Introduction

This article describes a new approach to mechanical engineering. Machines in line with this new concept are called "RELAZ". The term RELAZ was originally coined as an abbreviation for (REkuperačné LAnové Zariadenia). It refers to special forest ropeways that use the potential energy of trees growing in the mountains, for which the term 'mountain energy' was coined. It represents an alternative and renewable energy source for driving forest machines in mountain areas. RELAZ has now broadened its scope to include machines whose technical solutions are based on high performance batteries, enabling the machine to store and accurately control energy while in operation. The advantages of this new approach to mechanical engineering are particularly evident in economic and ecological terms.

The idea for RELAZ devices originated at the Technical University of Zwolę, and this article presents the most important results of the research and development work carried out at the University between 2006 and 2019.

The world novelty of RELAZ devices is confirmed by patents for inventions and utility models. At the beginning of 2015, 20 domestic and 6 foreign patents [1, 2, 13-32] were granted for RELAZ design perfection. At present, other applications for patents for inventions are pending. The quality of the technical solutions has been confirmed by awards and honours. In 2010 we received the Jan Bachyl Award for the development of a gyroscopic cableway, and in 2014 we received the President's Award from the Office of the President - Prize of the President of the Industrial Property Office of the Slovak Republic for the Hadva ropeway solution (ropeway powered by hydrogen fuel cells).

RELAZ devices are the result of several projects, theses and diploma theses. The basic principles have been tested using functional models. The concept of special forest roads that utilise mountain energy for their operation was first introduced by VEGA project 1/3526/06 under the title "Study of new technical and technological principles for wood skidding", which was developed in the framework of grant KEGA 3/6448/08. A machine design theory has been developed by Stefan Ilczyk, PhD, in his dissertation entitled "A Study of the Operating Principles of Regenerative Roofing Systems" [3]. The thesis was successfully defended in the field of agricultural and forestry mechanisation at the Faculty of Forestry Engineering in 2009. The


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proposed principles were practically tested on functional models. One of them was developed by the engineer Piotr Schmal in his diploma thesis “Flywheels and their use in gyroscopic ropeways” [4]. The result of the diploma work was a functional model of a gyroscopic ropeway, which is the first of its kind, which has no analogues in the world so far.

Other students who took part in RELAZ device research in their diploma theses and made significant contributions to the development of the subject include engineers J. Potok, M. Grad, A. Sabon, F. Pustovka, S. Bator and L. Dugas. Potok, M. Gradski, A. Szabon, F. Pustovka, S. Bator and L. Dugas.

From 2010 to 2012 RELAZ applied research was carried out as part of the RELAZ I project “Applied research and development of special wire rope systems. Special wire rope trolley”, ITMS 2620220036 and RELAZ II: “Applied research and development for special wire rope solutions. Special Flywheel”, ITMS 2620220035, which were funded by the Ministry of Education, Science, Research and Sport of the Slovak Republic and from EU structural funds. Between 2013 and 2015, basic research on new operating principles of wire rope trolleys for RELAZ devices continued in the framework of VEGA project 1/0931/13. The study of RELAZ devices was implemented in the teaching process at the Faculty of Forestry at the Technical University in Zvolen with the support of the Ministry of Education, Science, Research and Sports of the Slovak Republic within the KEGA project No. 011TU Z-4/2015.

Research aimed at developing a special power flywheel for storing rock energy was carried out in an underground laboratory (fig. 1). The laboratory was built as part of the RELAZ I and RELAZ II projects.

*Fig. 1.* Underground laboratory for powerfly wheels of RELAZ devices

RELAZ devices are currently being researched as part of Ondrej Szurkowski's doctoral thesis “Research of new alternative fuels and propulsion systems in selected forestry technologies”. The aim of this work is to investigate RELAZ hydrogen ropeways with direct combustion of electrolysis gas (a mixture of hydrogen and oxygen). The results of his thesis topic will be described in a separate article.

An international team of scientists is currently working on RELAZ devices. Cooperation under agreements is carried out with M. T. Kalashnikov Izhevsk State Technical University, BNTU (Minsk) and M. K. Ammosov North-Eastern Federal University (Yakutsk). The partner universities are involved in developing the solution with their extensive experience in researching the reliable operation of machinery in the extreme conditions of North-Eastern Siberia and the swampy areas of Belarus.

**The purpose** of the study is to investigate the possibility of using renewable mining energy, developing a concept for a machine energy subsystem called the “RELAZ device”.

**Approaches used**

Total energy consumption in the European Union decreased by more than 10 % between 2005 and 2015, reaching almost 1,500 million tonnes of oil equivalent (Mtoe) in 2015. (For comparability, the energy content of different fuels is converted to oil equivalents.)

This significant reduction was due in particular to the growing share of renewable energy sources. The development of primary energy consumption (renewable and non-renewable energy sources) in the EU and targets for 2020 and 2030 are shown in Figure 2 [5].

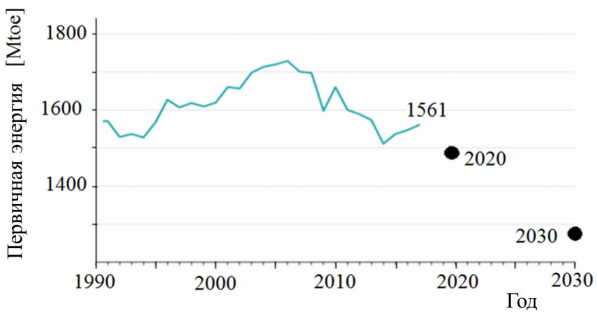


*Fig. 2.* Primary energy consumption in the EU 1990-2017 (source: Eurostat)

The share of renewable energy in the EU's total energy consumption is clearly increasing. From 6.5 % in 2004, the share was 17.0 % in 2016 [6]. In the long term, this share will continue to grow, and the use of woody biomass can also contribute to this in countries with high forest cover.

Wood is essentially a concentrator of solar energy. It can be recovered through burning and gasification. In forestry, however, there is another opportunity to make a significant contribution to saving fossil fuels. This is using the potential energy of trees in the mountains. Trees in the mountains are concentrators of solar energy, not only in chemical form, which is released during combustion and gasification, but also in mechanical form. In physical terms, this is potential energy. The value of this energy, $W_p$, is defined by the relation

$$W_p = mgh, \qquad (1)$$

where $m$ is the mass of the tree, kg; $g$ is the acceleration of the Earth's gravity, m/s$^2$; $h$ is the height difference when skidding the wood, m.

As this energy is possessed by trees growing in the mountains, we will call it mountain energy.

Let the trunk of a tree have weight $m$ = 1500 kg and the height difference it has to overcome when skidding, $h$ = 400 m (picture 3). Then the amount of mountain energy $W_{he}$ that this tree contains,

$$W_{he} = mgh = 1500 \cdot 10 \cdot 400 = 6.$$

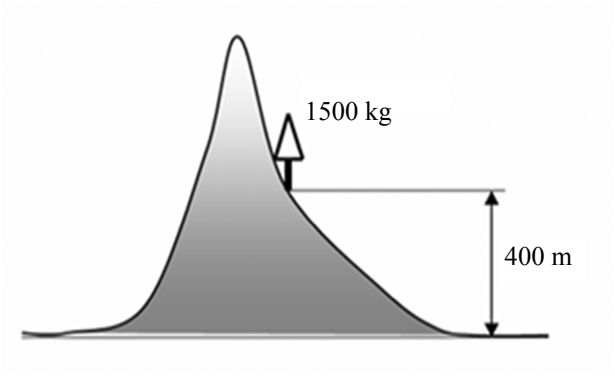


*Fig. 3.* For tree $W_{he}$ calculation

In mountainous Slovakia 5-9 million m$^3$ of timber is harvested annually. Let us assume that the total weight of timber from annual logging is $m$ = = 5 million tonnes and that the average height difference when logging is $h$ = 400 m. Calculate the total amount of mountain energy of trees $W_{he}$ and the equivalent amount of fuel (PHM):

$$W_{he} = mgh = 5\,000\,000\,000 \cdot 10 \cdot 400 =$$
$$= 2 \cdot 10^{13} \text{ J} = 2 \cdot 10^7 \text{ MJ}.$$

1 kg of PHM contains 44 MJ of energy (specific energy),

1 kg of PHM contains 44 MJ of energy (mountain energy). Then the equivalent amount of fuel that stores $2 \cdot 10^7$ MJ of mountain energy,

$$m_{PHM} = \frac{2 \cdot 10^7}{44} = 454545 \text{ kg}.$$

This is a significant amount of energy that is currently lost in the braking systems of forestry machines. If we could harness this energy, it would save a great deal of fuel and money each year.

The most suitable technical means of harnessing the mountain energy of trees is forest cable cars. Such forest cable cars, which store mountain energy and then use it to return an empty wire rope car back to its bedrock, and to pull the load onto the wire rope, were responsible for the creation of the term RELAZ, which is an abbreviation of the term Rekuperačné LAnové Zariadenia (from Slovak - regenerative rope device). Their technical solution will be described in detail in a separate chapter.

Let the weight of an empty ropeway trolley be $m$ = 300 kg. Let us calculate how much energy $W_{lv}$ is needed to pull it to the end of the route with an altitude difference of $h$ = 400 m:

$$W_{lv} = mgh = 300 \cdot 10 \cdot 400 =$$
$$= 1\,200\,000 \text{ J} = 1.2 \text{ MJ}.$$

Consequently, 1.2 MJ of energy must be expended. After skidding the tree with the RELAZ according to Fig. 2 and relation (1) and moving the empty te-tree back into the forest, the following remains

$$6{,}0 - 1{,}2 = 4{,}8 \text{ MJ}.$$

This represents 80 % of the available mining energy in Whe, which can be used to pull an additional load from the side under the carrying rope.

The environmental aspect of mining energy is closely linked to fuel savings (PHM) and the reduction of exhaust emissions from combustion engines.

Today mountain energy is lost in the braking systems of ropeways, tractors, harvesters, forwarders, vehicles etc. This causes their warming, which can be considerable. Above a certain critical temperature, the friction coefficient falls off due to the formation of burnt metal which can have serious consequences for operational safety. This is why a so-called relief brake is used on machines of standard construction. The following unloading brake solutions are used for timber ropeways: aerodynamic and eddy-current based inductive brakes.

In the past, loggers have had positive experiences with mountain energy. They used it to transport logs from mountains to valleys for short distances by means of logging trucks, logging trays, as

well as by rafting timber on rivers for long distances [7, 8]. At present the water transport in Slovakia is used only for recreational purposes, although this method of timber transportation is still used worldwide - in the Russian Federation, Canada and Finland.

Nowadays the use of mountain power is encountered only in rare cases when logs are skidded from distant mountainous areas, when logs are skidded manually with gravity skidding, and when skidders use portable skidders. Portable skidders consist of 2-3 m long plastic or galvanised sheet metal chutes.

This article takes us back to the idea of using mining energy in a new and technically sophisticated way. One characteristic feature of this new approach is that mining energy is used to power the machines. Machines designed with a new alternative drive system, which harvests potential energy from trees growing in the mountains, are called RELAZ devices.

**Operating principle of RELAZ devices**

Modern forest ropeways are complex mechatronic systems. They are powered by internal combustion diesel engines. The generally high energy consumption and even losses in modern machines with internal combustion engines - diesel engines are around 40 % efficient, gasoline engines around 30 % - cannot be solved by improving the design of individual components or by improving the component base. An entirely new approach to vehicle design is required, particularly in the energy subsystem. System features and precise energy management are the hallmarks of this new approach. The energy subsystem is named RELAZ, and the machines it is equipped with are called “RELAZ devices”. The heart of the RELAZ energy sub-system is the powerful energy storage device, which can continuously store, then retrieve energy. The working principle of a RELAZ energy sub-system is shown in Figure 4. 4.

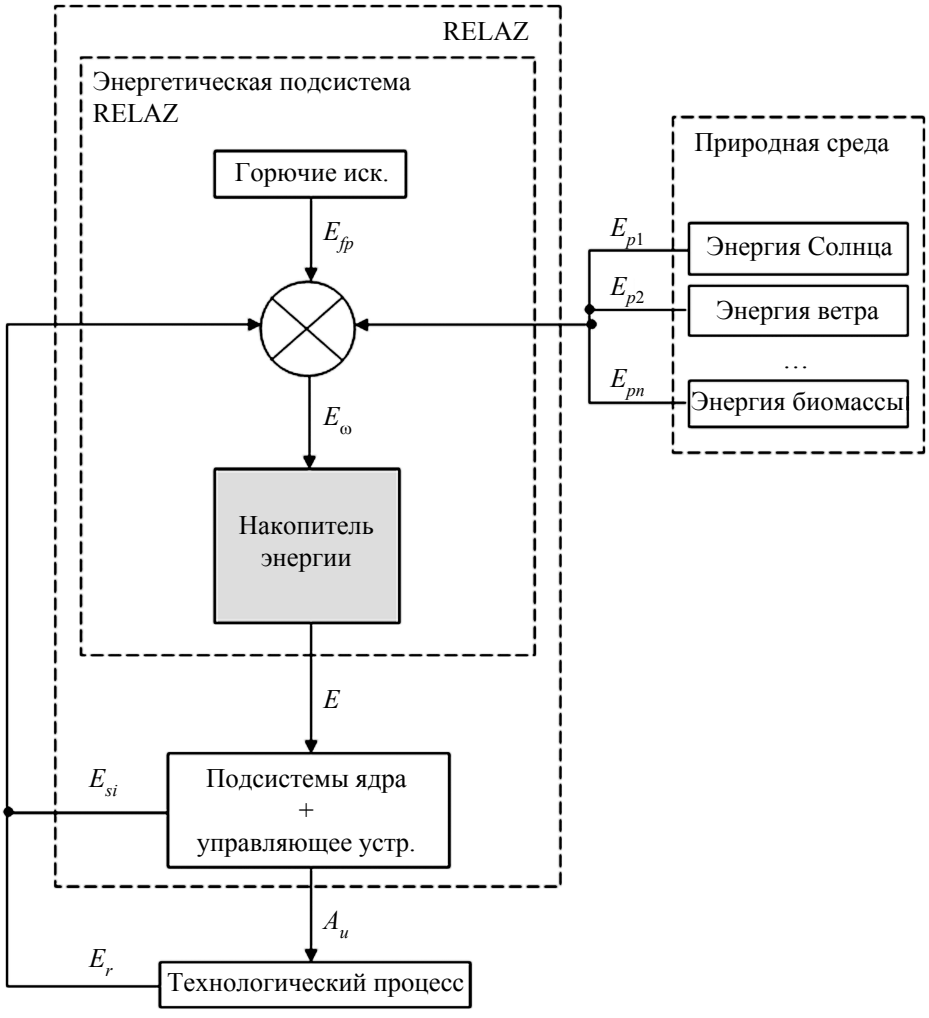


*Fig. 4.* RELAZ devices structure

The accumulator stores: $E_{fp}$ - energy derived from fossil fuels (diesel, petrol); $E_{si}$ - internal dissipation of machine power, which is converted into a form suitable for storage in the accumulator; $E_r$ - recovered energy, i.e. the energy generated during the technological process; $E_{p1}$, $E_{p2}$, ..., $E_{pn}$ - free energy from natural sources. This is an additional energy source which can lead to considerable fossil fuel savings in the long term.

In the case of forest ropeways, the energy generated in the $E_r$ process can be considerable. This special energy, referred to as mountain energy, is currently only used in very limited quantities, if at all.

What sets RELAZ machines apart from conventional machines is the use of energy storage, which enables precise energy management while the machine is in operation. Energy is stored in the accumulator, and so far energy has been wasted in and around the machine. When the machine is running, this stored energy is transformed back into useful work.

The following requirements apply to the energy storage devices of working machines.

1. large capacity, J, i.e. they must be able to store a large amount of energy.

2. High energy density, $J \cdot kg^{-1}$, i.e. they must be able to hold a large amount of energy per 1 kg of battery weight.

3. High power, $W \cdot s^{-1}$, i.e. they must be able to deliver a large amount of energy in a short period of time.

4. High efficiency, %, i.e. the ability to store energy for a long time.

5. They must be eco-friendly.

According to the way energy is stored, accumulators can be divided

- mechanical - springs, weights, flywheels;
- pneumatic - pressure vessels with a gaseous medium;
- hydraulic - pressure vessel with a liquid medium;
- electrochemical - batteries, fuel cells;
- electrostatic - capacitors and supercapacitors;
- electrodynamic - superconducting coils.

**Analysis of results**

The amount of energy stored in the battery (see fig. 4):

$$E_{\omega} = E_{fp} + E_{si} + E_r + E_{p1} + \ldots + E_{pn}.$$

Based on the relationship between the energy Eω going into the battery and the energy $E$ taken out of the battery (see Figure 4), three modes can occur during operation.

1. If

$$\left(E_{\omega} \geq E\right) \wedge \left(E_{fr} = 0\right) \wedge$$
$$\wedge \left(E_{si} + E_r + E_{p1} + \ldots + E_{pn} \neq 0\right),$$

quasi-wheel operation occurs, i.e. there is enough energy from alternative sources to keep the battery charged or, if there is excess energy, to recharge it, so there is no need for energy from fossil fuels.

2. If

$$\left(E_{\omega} \geq E\right) \wedge \left(E_{fr} \neq 0\right) \wedge$$
$$\wedge \left(E_{si} + E_r + E_{p1} + \ldots + E_{pn} \neq 0\right),$$

economy mode is activated. Both fossil fuel and alternative sources of energy are used to maintain the battery charge.

3. If

$$\left(E_{\omega} \geq E\right) \wedge \left(E_{fr} \neq 0\right) \wedge$$
$$\wedge \left(E_{si} + E_r + E_{p1} + \ldots + E_{pn} = 0\right),$$

classic mode occurs. In this mode, RELAZ will operate as a standard machine type, i.e. all of its energy requirements will be covered by fossil fuel.

4. If

$$\left(E_{\omega} = 0\right) \wedge \left(E = 0\right),$$

discharging mode occurs. There is enough energy in the battery to operate the unit. This will apply especially at the end of the day before disassembly.

From the description of the operating modes, it can be seen that RELAZ devices can be classified as so-called hybrid devices.

For RELAZ device efficiency in classic mode

$$\eta = \frac{A_u}{E_{\omega}} = \frac{A_u}{E_{fp} + E_{si} + E_r + E_{p1} + \ldots + E_{pn}} = \frac{A_u}{E_{fp}}.$$

It is similar to machines with a conventional energy subsystem. However, analyses and computer simulations show that RELAZ is significantly more efficient in this mode. Generally speaking, when a RELAZ fuel subsystem is added to a conventional combustion engine vehicle, fuel consumption (fossil fuel) decreases by a factor of 2.5 to 4.0 due to higher efficiency η. The explanation for this phenomenon is that the RELAZ power sub-system uses the combustion engine to charge the battery, also in the classic mode, rather than driving the unit. This allows the engine to continue operating at its optimum speed point during the charging process at nominal speed nm, i.e. with minimum fuel consumption (Figure 5).

In the modes of energy-saving and quasi-ever engines, the efficiency connected with energy $E_{fp}$, received from fossil fuel, increases considerably due to economy at the expense of use of alternative energy sources $E_{si}$, $E_r$, $E_{p1}$, $E_{p2}$, …, $E_{pn}$ and approaches to 1 or even exceeds it. Even in a quasi-ever motor, this efficiency is close to ∞ (infinity). Of course, this is not a classical perpetual motion machine, as it may seem at first sight. The point is that RELAZ does not get the energy it needs to run, but the energy is derived entirely from alternative energy sources.

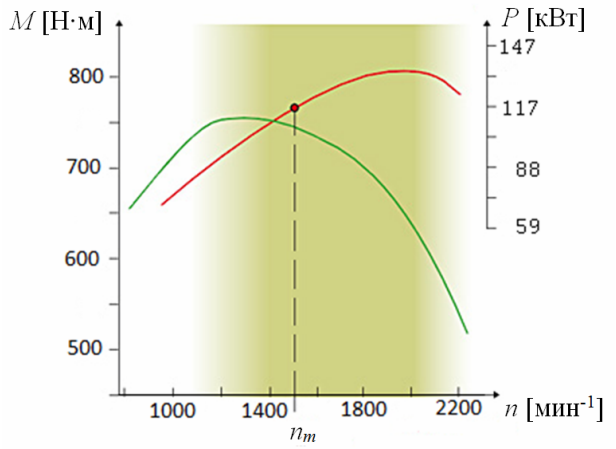


*Fig. 5.* Engine characteristics related to revolutions per minute

The amount of energy supplied to a machine depends on the intensity of the machine's operation, the so-called output $W$. The capacity $W$ is given in physical units, e.g. $m^3$/h, ha/h, kg/h, etc. On the basis of the minimax theory of Prof. A. Janeczka [9], it is assumed, that if the productivity of a machine grows linearly, the energy increases linearly, the energy $E$ at the input increases exponentially. If we relate the energy E at the machine's input to its capacity $W$, we obtain the so-called specific energy $Q$:

$$Q = \frac{E}{W}.$$

For each machine, it is possible to find the operating mode at which it works optimally, i.e. it spends the least amount of energy per unit of physical work. This mode is defined as follows:

$$\frac{\partial Q}{\partial W} = 0.$$

If the machine works near the optimum $W_{opt}$ point (in the optimum $W_{opt}$ range), it is correctly selected (Fig. 6). When operating to the left of $W_{opt}$ - the machine in question is not powerful enough, to the right of $W_{opt}$ - the machine in question is very powerful. For conventional machines, the optimum range is relatively narrow. In order to be able to select the right machine for the job, there must be a whole group of machines with different installed capacities. The theory of minimax therefore tells us how to select a machine which does the job with as little energy as possible.

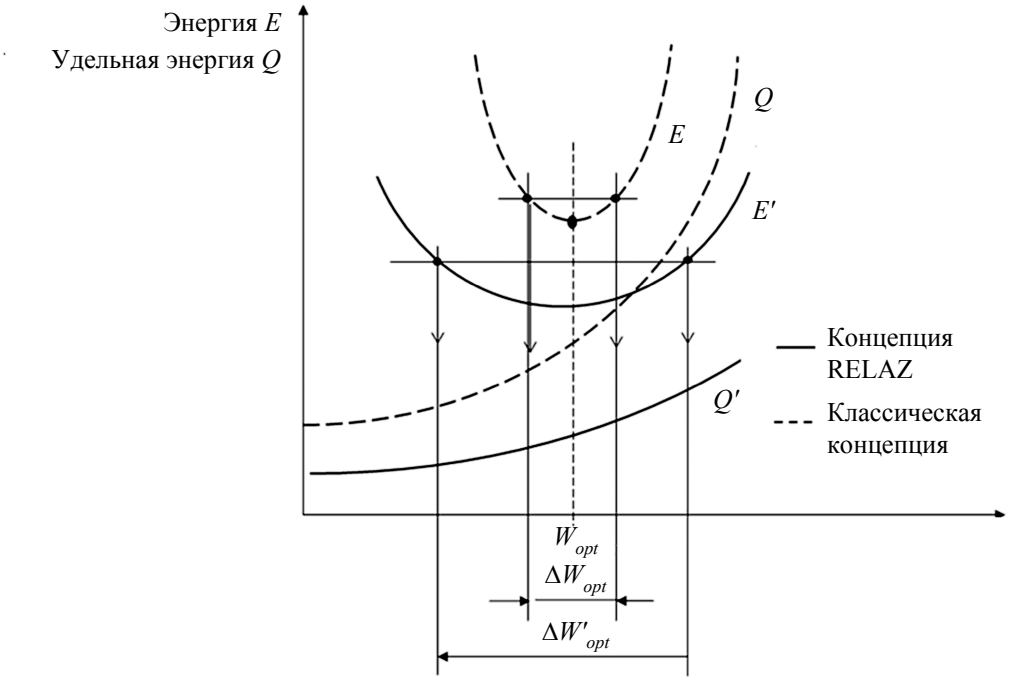


*Fig. 6.* Performance characteristics

Applying the minimax theory to the RELAZ devices, the results are shown graphically in Fig. 6 by continuous curves $Q'$, $E'$. It is analytically established that there $Q$ и $Q'$ is a relationship between $Q' < Q$ and that the specific performance curve $Q'$ of RELAZ devices has a smaller gradient, i.e. steepness, as the specific performance curve of Q machines of classical design. Then

$$\text{Grad}\, Q' < \text{Grad}\, Q.$$

The results obtained confirm the prospectivity and competitiveness of RELAZ devices.

During the period from January 2007 to March 2008, research was conducted on the impact of mining energy on the environment.

On January 2007 and March 2008, the impact of mining energy on the environment was studied. The research was carried out by J. Potok [10] on a forest road W30, manufactured in Switzerland. The data are summarized in the table.

From the data in the table it is clear that during the period under consideration, 6054 m3 of wood was skidded by the cable car downhill and 1220 L of diesel fuel were consumed at the amount of 51972 Sk (in 2008 prices), while 4 299 283 J of mountain energy were extracted from the forest plantations.

The analysis of the empirical data and calculations shows, that the use of RELAZ ropeway under the given conditions of production would save 780 L of diesel fuel, which is 64% of economy.

**Research results summary**

| Part | Volume of cuttings wood, $m^3$ | Fuel consumption (PHM), L | Real costs fuel (PHM), Sk | Mass of cutted wood, kg | Mountain energy, J |
|---|---|---|---|---|---|
| Downhill | 6 054 | 1 220 | 51 972 | 4 838 635 | 4 299 283 647 |
| Uphill | 1 137 | 366 | 15 592 | 841 380 | 645 070 284 |
| Total | 7 191 | 1 586 | 67 564 | 5 680 015 | 4 944 353 941 |

The claimed savings for this job could have been higher if the ropeway had moved 1,137 $m^3$ of wood downward instead of upward.

When granting patents for inventions, the principle of territoriality is applied, i.e. a patent for an invention is granted, providing protection to its owner only in the territory of the state where the patent was registered. This does not prevent the solution from being developed in other countries of the world. For example:

1. The ELFOREST principle, developed by the Swedish company ELFOREST TECHNOLOGIES. An electric battery is used as an energy accumulator [11].

2. Kohler (Austria) is the owner of the patent DE 10 2011 122 121 for a forest ropeway solution. A supercapacitor is used as a powerful energy storage device.

3. GANTNER (Austria) offers on the market the environmentally friendly rope winch GW 350E, which uses a powerful electric battery [12].

**Conclusions**

The article describes a new alternative energy source called "mountain energy. This energy is available to foresters day and night in all weathers. The article describes a new approach to the design of machines, which allows the use of mountain energy. Distinctive features of this new approach to mechanical engineering are systematic and precise control of energy consumption in the operation of the machine. The main part of the devices within this new concept is a powerful energy accumulator. The most suitable conditions for the use of mountain energy to drive machines are in the forest zone, especially on forest ropeways.

The realization of the technical solution was carried out at the Technical University in Zvolen (Slovakia) in the period 2006-2008 and the device itself was called “RELAZ device”.

RELAZ solution is protected by several Slovak and foreign invention patents that are a proof of the world novelty of the solution. The proposed principles were practically tested on functioning models.

RELAZ devices are hybrid devices. The combustion engine is used only for charging the high capacity accumulator. The charging process is carried out at the rated speed of the internal combustion engine, which reduces fuel consumption by a factor of 3-4. That's why RELAZ units can be advantageously used not only in mountainous terrain, but also on the plains.

The optimal mode of RELAZ devices was found, which has a wider range than that of classical machines. The specific energy of RELAZ devices is less than that of the classical machines. It is proved, that a RELAZ ropeway on a W30 ropeway manufactured in Switzerland saves 780 L of diesel fuel per year, which corresponds to a saving of 64 %. The achieved results show that RELAZ products are showing good perspectives and are highly competitive.

Currently, further research of RELAZ devices at the Technical University in Zvolen is being conducted as part of Ondrej Šurkovský's doctoral thesis "Research of new alternative fuels and power plants based on electrolysis gas in selected forestry technologies".

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**Устройства RELAZ**

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*Самым большим источником энергии в нашем мире является Солнце. В данной статье обсуждается одна из малоизвестных форм солнечной энергии. Этот новый альтернативный и возобновляемый источник энергии был назван «горная энергия», потому что его источником являются деревья, растущие в горах. Чтобы использовать его для привода машин, была предложена новая концепция энергетической подсистемы машины. Машины в соответствии с этой новой концепцией получили название «устройства RELAZ». Техническое описание этих гибридных устройств составляет вторую часть статьи. Устройства RELAZ изначально предназначались для лесозаготовителей, работающих в горных районах. Однако принципы, используемые в их конструкции, позволяют более эффективно применять машины с двигателями внутреннего сгорания в целом. Устройства RELAZ – это гибридные устройства. Они оснащены двигателем внутреннего сгорания, который служит только для зарядки мощного аккумулятора энергии. Процесс зарядки осуществляется при номинальной скорости двигателя внутреннего сгорания, что позволяет в 3–4 раза снизить расход топлива. Поэтому устройства RELAZ могут выгодно использоваться не только в горной местности, но и на равнине. Найден оптимальный режим работы устройств RELAZ, который имеет более широкий диапазон, чем у классических машин. Удельная энергия устройств RELAZ меньше, чем у классических машин. Было установлено, что использование канатной дороги типа RELAZ на лесной канатной дороге W30, произведенной в Швейцарии, может сэкономить 780 л в год дизельного топлива, что составляет 64 % экономии. Полученные результаты подтверждают перспективность и конкурентоспособность устройств RELAZ.*

**Ключевые слова:** горная энергия, устройства RELAZ, рекуперация энергии, оборудование механизации лесного хозяйства, лесные канатные дороги.

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