ЕЛЕКТРИЧНИЙ ТРАНСПОРТ, ЕНЕРГЕТИЧНІ СИСТЕМИ ТА КОМПЛЕКСИ

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HYDROELECTRIC ROAD RAMP

Purpose. The purpose of the study was to elaborate on a renewable source of energy using daily vehicles' traffic. The research question was how to produce electricity by using vehicle's kinetic energy and water-contained energy. In this paper «hydroelectric road ramp» is described as an auxiliary energy source which can be used in smart cities. **Methodology.** By conducting the literature review of adjacent methods and existing inventions, combining principles of work of these inventions, the system for producing electricity without destroying nature has been designed. **Findings.** Based on the supposition that 200 vehicles per hour pass over a ramp, the findings show that power generated by the system equals to 405,34 W. Considering the fact, that city roads function around the clock we can multiply the obtained result by 24 hours. Thus, we can accumulate a lot of electricity for efficient using in necessary goals. Even considering the fact that road capacity is different hour by hour, there is an opportunity to generate enough electricity for its conservation and further usage. **Originality.** From one side 'hydroelectric road ramp' is the system of generating electricity by using principles of work of conventional hydroelectric power station and pneumatic water sprayer, from the other side it is a speed breaker which may improve the safety conditions on the road. **Practical value.** The calculations we obtained led us to the theoretical conclusion that electricity getting from new source can be effectively used in the 'smart city' such as: powering street lights, traffic lights or serve as a complementary source of energy for e-mobiles charging points.

Keywords: alternative energy; kinetic energy; water-contained energy; electricity; smart city; speed breaker

Introduction

There is a fact that renewable energies are considered as proper alternative energy, which reduces carbon dioxide emission. This means renewable energy like wind energy, solar, tidal, biomass, geothermal which are not harmful for environment can be used as alternative. As a car passes over a speed breaker most of kinetic energy is wasted as heat in it. However, the speed bumps on roads, where huge amount of vehicle's kinetic energy is wasting, can be used to retrieve this kinetic energy and generating electricity [1].

There are some methods of converting vehicle's kinetic energy into electrical energy such as follows: «Electro-Kinetic Road Ramp' [2] which was tested in some countries and proved its effectiveness or 'Design of Power Generation Unit Using Roller Mechanism' which is implemented by using simple drive mechanism such as Roller, some interfaced Electrical components and chain drive Mechanism [6].

Nevertheless, we propose novel non-conventional method called 'hydroelectric road ramp' that is significantly different from the proposed by previous researchers. 'Hydroelectric road ramp' serves not only as a speed bump for traffic calming, but also it is a new method of generating electricity by using principles of work of conventional hydroelectric power station [7] and pneumatic water sprayer [10].

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Purpose

The purpose of the study was to elaborate on a renewable source of energy using daily vehicles' traffic. The research question was how to produce electricity by using vehicle's kinetic energy and water-contained energy. The calculation of power output has been calculated considering approximate identified variables. Also during the calculation we considered X vehicles per hour, however practical result can be distinguished from the theoretical one due to stochastic process of the vehicle's movement. We have presumed that electricity getting from new source can be conserved and used in traffic lights, powering streets or serve as a supplementary source of energy for electro mobility charging points.

This paper does not provide a detailed analysis of material properties and technical characteristics of the system elements such as turbine, electronic pressure controller, tank, etc., as well as cost calculation. The study is purely theoretical, as a practical experiment requires significant resources. Therefore, approximate initial numerical data which are shown in Fig.2 have been used during energy calculation.

Methodology

Publicly accessible sources like standards, scientific articles, and reports contain limited information on the proposed method of electricity generating. To overcome this shortcoming, further information is collected through the literature review of adjacent methods and existing inventions. Combining principles of work of these inventions, the necessary result was received. Fig. 1 illustrates the research approach, which includes a literature review of several relevant inventions in order to collect information and create a non-conventional method of producing electricity.

The calculation methodology included the following steps:

– calculation of the volume of the reservoir;

a finding of the gauge pressure in the tank after n number of pumps;

– amount of water in each stroke of the pump has been found;

– identification of an absolute pressure inside the tank;

– determination the velocity at which the water leaves the tank using the Bernoulli equation;

– calculation of the volume rate of flow;
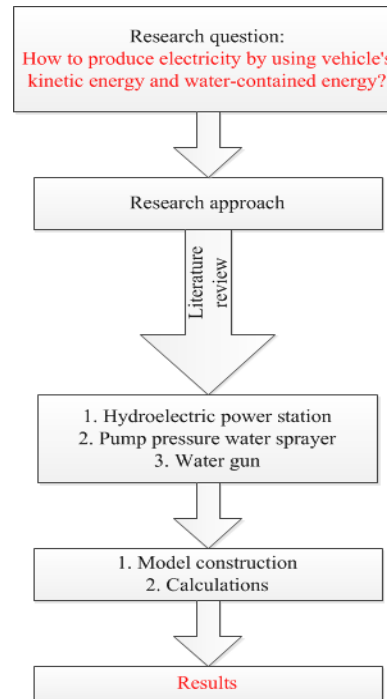
– calculation of power generated by the system.

Fig. 1. Research methodology

Model description

The ramp serves as launching mechanism [4] for hydroelectric power station by harnessing the kinetic energy of automobiles that drive over ramp. It is not dangerous for the vehicles and cannot become the cause of waste petrol when a car passes over it [5]. Because on the road surface it serves only as a conventional speed breaker, however in underground it connects with mini station producing electricity with water usage [8]. Fig. 2 represents the ramp structure and principle of work.

Slab of the ramp connects with the cylinder which serves as a piston rod of the pump. Every time automobiles pass through this plate the piston moves down and up pumping air into a partially water-filled tank. Motion is possible thanks to the spring installed under the plate. If necessary, several springs can be installed. The reservoir is airtight, but it has valve to let the incoming air in from the pump.

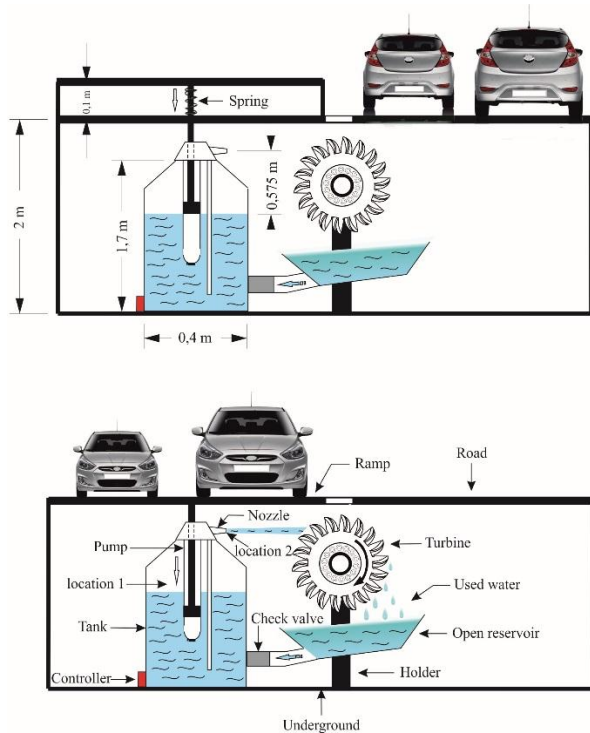ЕЛЕКТРИЧНИЙ ТРАНСПОРТ, ЕНЕРГЕТИЧНІ СИСТЕМИ ТА КОМПЛЕКСИ

Fig. 2. Energy ramp structure

As more air is pumped in, the air in the reservoir is compressed, increasing in pressure; the water is also pressurized by the now compressed air. Upon opening the nozzle valve, the pressurized water is pushed out through the nozzle as the air attempts to re-equilibrate with atmospheric pressure [3].

In case of our study, the nozzle valve is an automatically controlled valve operated by the electronic pressure controller. The controller activated automatically according to the adjustments of the specialists, i.e., when the pressure in tank reaches certain value or is excessive. It means that every time, when electronic pressure controller identifies pre-defined value of pressure in the reservoir it transmits a signal to open the nozzle valve.

This air pressure system allows production of a solid, continuous stream of water. The water jet rotates the turbine connected with the generator which produces electricity [9]. In the case of this research, we supposed that it is necessary to use special turbine that must be created by 'pelton turbine' principle. All necessary dimensions must be performed by professionals.

The water, bouncing off the turbine, flows into an open reservoir located under the turbine. Then it flows again into the main tank through the non-return valve. Thus, the system is constantly recycling the same water. Therefore 'Hydroelectric road ramp' can be counted as renewable energy source.

To start the system, only the initial water filling of the container is required. Refilled is necessary only in emergency cases such as water leakage, evaporation of water, repair of the structure, etc. However, the limitation of this design is the tank cannot be refilled unless depressurized. Opening a pressurized reservoir while there is pressure remaining in the system can result in copious local water spray or even an unexpected consequence.

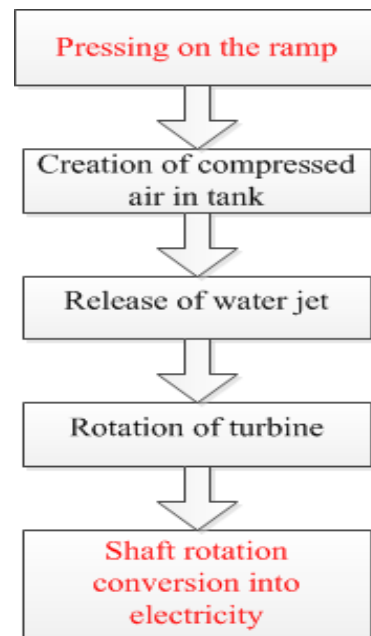Fig. 3 illustrates the operation of the 'hydroelectric road ramp'

Fig. 3. Process diagram of the ramp

Findings

For all calculation, we used assumed dimensions of the ramp which is shown in Fig. 2. Since the tank represents a combination of cylinder and frustum then the total volume of the tank is the sum of their volumes:

$$V_t = V_c + V_f . \qquad (1)$$

The volume of cylinder:

$$V_c = \pi r^2 h , \qquad (2)$$

$$V_c = 3,14 \times 0,2^2 \times 1,5 = 0,18 \; m^3 . \qquad (3)$$

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The volume of frustum:

$$V_f = \frac{1}{3}\pi h (R_1^2 + R_1 R_2 + R_2^2), \qquad (4)$$

$$V_f = \frac{1}{3} \times 3,14 \times 0,2(0,2^2 + 0,2 \times 0,1 + 0,1^2) =$$

$$= 0,014 \ m^3. \ (5)$$

The total volume of tank:

$$V_t = 0,18 + 0,014 = 0,194 \ m^3 = 194 \ l. \qquad (6)$$

The assumption is made that volume of water equal 150 l. The volume of air is then the difference between the volumes of the tank and the water within it:

$$V_a = V_t - V_w, \qquad (7)$$

$$V_a = 194 - 150 = 44 \ l, \qquad (8)$$

To identify an absolute pressure at location 1 we used the following formula:

$$P_a = P_o + P_m, \qquad (9)$$

where, P_o – atmospheric pressure (101325 Pa); P_m – gauge pressure.

Using an assumption that 200 vehicles per hour pass over ramp, we calculated the gauge pressure in a tank after n pumps:

$$P_m = \frac{n P_o V_p}{V_t - n V_p}, \qquad (10)$$

where, n – number of pumps (n=400), because one car pushes on slab two times by front and rear wheels; P_o - atmospheric pressure (101325 Pa); V_p – amount of water in each stroke of the pump; V_t – total volume of tank.

Amount of water in each stroke of the pump can be found by next formula:

$$V_p = \frac{V_w}{n}, \qquad (11)$$

where, V_w – volume of water; n – number of pumps

$$V_p = \frac{150}{400} = 0,375 \ (l). \qquad (12)$$

Thus, gauge pressure equal:

$$P_m = \frac{400 \times 101325 \times 0,375}{194 - 400 \times 0,375} = 345426 \ (Pa). \ (13)$$

Consequently, location 1 has the following absolute pressure:

$$P_a = 101325 + 345426 = 446751 (Pa). \qquad (14)$$

To define the velocity at which the water leaves the tank is used the Bernoulli equation. The Bernoulli equation is used to connect two locations within a single fluid. We chose our two locations as being at the surface of the water in the reservoir (location 1) and at the exit of the nozzle (location 2). This means that:

$$P_1 + \frac{1}{2}\rho \upsilon_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho \upsilon_2^2 + \rho g h_2, \qquad (15)$$

where, P_1– absolute pressure at location 1; ρ– density of water (1000 kg/m^3); υ_1– water velocity at location 1. We approximate that $\upsilon_1 = 0$; g – acceleration of gravity ($g = 9,81 m/s^2$); h_1– height between location 1 and location 2 ($h_1 = 0,575 m$); P_2– pressure at location 2. Location 2 touches the air and has pressure $1 \ atm = 101325 \ Pa$; υ_2– water velocity at location 2; h_2– height at location 2. This variable is neglected, which means that $h_2 = 0$.

In this case the equation acquires a new form:

$$\upsilon_2 = \sqrt{\frac{2(P_1 + \rho g h_1 - P_2)}{\rho}}, \qquad (16)$$

$$\upsilon_2 = \sqrt{\frac{2 \times (446751 + 1000 \times 9,81 \times 0,575 - 101325)}{1000}} =$$

$$= 26,5 \ (m/s). \ (17)$$

If the water exits the tank through the hole with diameter 0,02 m, the volume rate of flow can be calculated by this equation:

$$Q = A\upsilon = \pi r^2 \upsilon, \qquad (18)$$

$$Q = 3,14 \times 0,01^2 \times 26,5 = 0,008 \ (m^3/s). \ (19)$$

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Despite the fact that in modern conditions under favorable working conditions of the best samples hydraulic efficiency can achieve 94 – 95 %. We decided to consider that efficiency of proposed mechanism is about 50%, which means that $e = 0,5$. Power generated by the system can be calculated with the next formula:

$$P = e\frac{\Delta E}{\Delta t} = e\frac{\Delta mgh}{\Delta t} = egh\frac{\Delta m}{\Delta t}, \qquad (20)$$

where, e – efficiency of mechanism; g – acceleration of gravity ($g = 9,81 \ m/s^2$); h – head in meters. Since the pressure at location 2 equal $1 \ atm$, then $h = 10,33$ (m); $\frac{\Delta m}{\Delta t}$ — flow volume in $kg / \sec$.

Thus,

$$P = 0,5 \times 9,81 \times 10,33 \times 8 = 405,34 \ (W). \quad (21)$$

Originality and practical value

From one side 'hydroelectric road ramp' is the system of generating electricity by using principles of work of conventional hydroelectric power station and pneumatic water sprayer, from the other side it is a speed breaker which may improve the safety conditions on the road. This is a new system which is located underground and may use different types of water including wastewater (rain, snow, hail) with preliminary filtration. Using the Bernoulli equation, other different formulas, and assumptions, we calculated the approximate power generated by the system. The calculations we obtained led us to the theoretical conclusion that electricity getting from new source can be effectively used in the 'smart city' such as: powering street lights, traffic lights or serve as a complementary source of energy for e-mobiles charging points.

Conclusions

The amount of electricity generating using proposed system is flexible, because the movement of vehicles on the road is a stochastic process. It is impossible to predict exact quantity of vehicles pass over ramp. Moreover, intensity of movement depends on different conditions and circumstances such as rush hours and traffic jams. Nevertheless, calculation result's based on the supposition that 200 vehicles per hour pass over ramp looks enough fair and the power generated by the system equals to 405,34 W. Considering the fact, that city roads function around the clock we can multiply the obtained result by 24 hours. Thus, we can accumulate a lot of electricity for efficient using in necessary goals. Even considering the fact that road capacity is different hour by hour, there is an opportunity to generate enough electricity for its conservation and further usage.

Among the main contribution of the paper we highlight the possibility of producing almost free electricity based on renewable energy. Our results may have high relevance for innovation and development. Key advantages of the proposed system are as follows:

– renewable source of energy;

– possibility to increase amount of electricity generating per hour;

– possibility to conserve and use electricity for different goals;

– possibility of modernization of proposed system.

As the practical application and improvement of the new method is an enormous and complex task, not only intuitively but also physically, future research is expected to proceed in several directions. Our future plans, based on this research, include:

– modernization of the ramp model by integration of information systems;

– detailed analysis of hardware and software model;

– significant increase of the shaft rpm using high pressure nitrogen gas (N_2) in system;

– addition of supplementary elements such as drain, filter, plumbing for using wastewater (rain, hail, snow, etc.);

– assessment of socioeconomic benefits (e.g. electricity cost reduction).

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ГІДРОЕЛЕКТРИЧНА ДОРОЖНЯ ЕСТАКАДА

Мета. Основною метою цього дослідження є розробка поновлюваного джерела енергії з використанням щоденного руху транспортних засобів. Проблема дослідження полягає в пошуку способу вироблення електрики з використанням кінетичної енергії автомобіля й енергії води. У цій статті гідроелектрична дорожня рампа описана як допоміжне джерело енергії, яке можна застосовувати в «інтелектуальних містах». **Методика.** Після огляду літератури щодо суміжних методів, наявних винаходів і об'єднання вивчених принципів роботи була запропонована екологічно безпечна система виробництва електроенергії. **Результати.** На підставі припущення, що за годину по естакаді проїжджають 200 автомобілів, установлено, що потужність, генерована системою, дорівнює 405,34 Вт. Беручи до уваги, що міські дороги працюють цілодобово, отриманий результат помножимо на 24. Таким чином, можна накопичити багато електроенергії для ефективного використання в необхідних цілях. Навіть з урахуванням того, що пропускна здатність дороги змінюється щогодини, є можливість виробляти достатньо електроенергії для її збереження й подальшого використання. **Наукова новизна.** З одного боку, гідроелектрична дорожня естакада – це система генерування електроенергії з використанням принципів роботи звичайної гідроелектростанції й пневматичного

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водорозпилювача, з іншого боку, вона виконує роль лежачого поліцейського, що може підвищити безпеку дорожнього руху. **Практична значимість.** Проведені розрахунки дозволили нам зробити теоретичний висновок, що отримання електроенергії з нового джерела можна ефективно використати в «інтелектуальному місті», наприклад, для живлення вуличних ліхтарів, світлофорів, або як додаткове джерело енергії для пунктів підзарядження електромобілів.

Ключові слова: альтернативна енергія; кінетична енергія; енергія води; електрика; «інтелектуальне місто»; лежачий поліцейський

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ГИДРОЭЛЕКТРИЧЕСКАЯ ДОРОЖНАЯ ЭСТАКАДА

Цель. Основной целью данного исследования является разработка возобновляемого источника энергии с использованием ежедневного движения транспортных средств. Проблема исследования состоит в поиске способа производства электричества с использованием кинетической энергии автомобиля и энергии воды. В этой статье гидроэлектрическая дорожная рампа описана как вспомогательный источник энергии, который можно применять в «интеллектуальных городах». **Методика.** После обзора литературы по смежным методикам, существующим изобретениям и объединения изученных принципов работы была предложена экологически безопасная система производства электроэнергии. **Результаты.** На основании предположения, что за час по эстакаде проезжают 200 автомобилей, установлено, что мощность, генерируемая системой, равна 405,34 Вт. Принимая во внимание то, что городские дороги работают круглосуточно, полученный результат умножаем на 24. Таким образом, можно накопить много электроэнергии для эффективного использования в необходимых целях. Даже с учетом того, что пропускная способность дороги изменяется от часа к часу, есть возможность вырабатывать достаточно электроэнергии для ее сохранения и дальнейшего использования. **Научная новизна.** С одной стороны, гидроэлектрическая дорожная эстакада – это система генерирования электроэнергии с использованием принципов работы обычной гидроэлектростанции и пневматического водораспылителя, с другой стороны, она выполняет роль лежачего полицейского, что может повысить безопасность дорожного движения. **Практическая значимость.** Произведенные расчеты позволили нам прийти к теоретическому выводу, что получение электроэнергии из нового источника может быть эффективно использовано в «интеллектуальном городе», например, для питания уличных фонарей, светофоров или в качестве дополнительного источника энергии для пунктов подзарядки электромобилей.

Ключевые слова: альтернативная энергия; кинетическая энергия; энергия воды; электричество; «интеллектуальный город»; лежачий полицейский

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