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RESEARCH OF POWER GENERATOR PROTOTYPE DEVELOPMENT AND INTEGRATION INTO AUTONOMOUS ROBOTIC SYSTEMS

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Abstract. *The aim of the research is to perform experimental research based on patented technology to improve the efficiency and applicability of the patented invention in the power supply circuits of autonomous robotic systems in order to improve electricity utilization and regeneration rates, ensuring longer autonomous operation of the robotic system. The article reviews the technologies of electricity generation and aspects of their practical application. Described research methodology and research stand. Presented the results and conclusions of the performed simulation tests of the prototype electrodynamic parameters. Proposals made for the integration of research results into the students practical educational process.*
Keywords: *robotic system, electricity generator, regeneration.*

Introduction

Our team is very young: it was formed in the first half of the year 2020. Members of the team - both teachers and students – are united by the idea to explore opportunities of creation of a generator for autonomic robotic systems. One of such systems accessible for research and not too complicated in the beginning can be an electric car. This system is partly autonomic in the aspect of its control; however, its electric circuit is fully autonomic.

The base of this research is a patented idea (the Patent No. LT-6714B; the Application No. 2019-065) (V. Matutis & M. Matutis, 2020). The patented invention was created upon striving to increase the distance covered by an electric car after a single charging its battery at a stationary charging station. The goal of the invention is use of a mobile electric power generator based on an environmentally friendly technology in combination with wind power (both

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kinetic and potential energy of air mass formed on movement of the car) that is equipped with a compensatory mechanism of a simple design (in principle, it is a component of an electric car involved in charging the battery during the car's movement). The mock-up of a wind turbine is presented in Fig.1 below.

Analyzing of analogous ideas shows that a majority of them do not achieve the efficiency required for practical application, because the losses exceed the expected level on a certain stage (phase) and the possible efficiency becomes negative (that means losses). So, the team agreed to analyze each phase and to carry out practical measurements on a test stand for searching the best efficiency for each of this phase; if possible, computer modelling media shall be applied or created for up-and-coming studies.

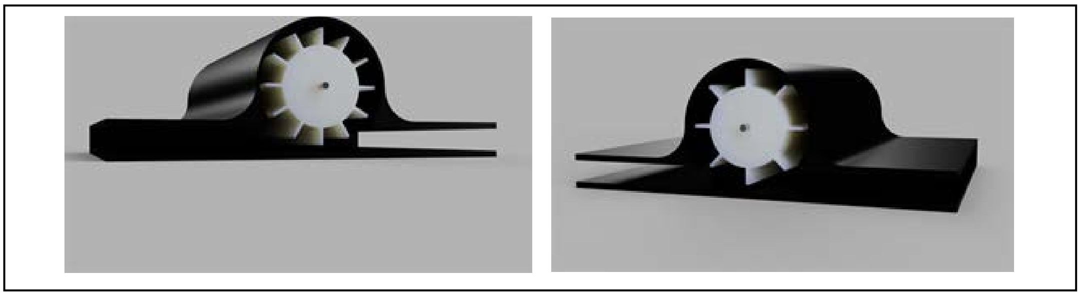

Figure 1 ***Wind Turbine Layout View***

To achieve the efficiency of a generator for electric cars that can provide a practical benefit, an integrated approach (Matutis, 2008) is required, because it involves mechanics, electromechanics, electronics and some other areas of practical physics. On movement of an electric car, transformation of air flow around it into electric power required for charging the accumulator is one of the possible versions. Use of air flow power is analyzed in studies related to practical application of wind power systems where it is tried to use kinetic energy of air flow to the maximum possible extent. It was decided to carry out a practical analysis of this aspect in the first phase. The key problem of the said phase was a need to establish the number of wings of a chosen wind turbine that would ensure the best efficiency. The chosen geometric design of the turbine (Fig.1) is the simplest and is sensitive to environmental impact to the minimum extent. The design of the wings is simple as well; however, it ensures positive efficiency (in mechanical aspect) because of the relevant ratio of force levers.

However, the most interesting and uncertain factor remains use of air flow efficiency depending on the number of turbine wings. Such a formulation of the run of the study enabled starting to create a laboratory stand upon applying the available means and involving students in the works. It was planned to print a majority of details for the mock-up by 3D printers – these works were useful for developing skills of the students in design and manufacture, improved their figurative thinking and their abilities to convey it. In addition, they included modelling, programming and practical manufacturing educative activities. The short involvement of students in the project was highly beneficial both for them and for the total process of education at the College.

While talking about the consequences of a long-term involvement in such a project and the benefit provided, it should be remembered that the essence of the study was integrated approach, i.e. complexity. In this multi-phase study, almost each phase was related to a new area, such as mechanics, electromechanics, electronics and so on. In addition, each of the said areas was bound with other ones, so maintenance of the positive efficiency on transfer from one phase to another required to understand the interaction of the said areas and their integrity and to take them into consideration. In the process of education, this predetermines the general mastering of the conception of the surrounding world's integrity that is very important for our young generation to survive in the period tormented by crises and to create the future for themselves and their children...

Talking about the methodology of the study, the most effective and simple (in the aspect related to the design of the stand) way to find an answer to the put question would probably be measuring the behavior of the turbine at constant air flow and variable number of turbine wings. For the said purpose, a large number of rotors of different configurations (with different numbers of wings) (Fig.1) shall be made using the available 3D printers. Upon taking into account later aspects of practical application, it would be purposeful to measure two parameters – the starting point when the turbine starts its movement (rotation) and the torque developed by the rotating turbine in its internal cavity. Measurements of the torque can be carried out on gradual increasing the load and observing the turbine rotational speed. Such a curve was drawn at the constant air flow (that remains the same on any changes of the turbine rotor's configuration or in absence of them) and describes a turbine with a certain number of wings. If we suppose that varying the number of wings causes changes of the turbine characteristics, these measurements will enable entering the relevant data to the programmed computer simulator and providing more detailed clarification of the results of practical measurements through their abstraction.

The opportunity of involvement in discussions on the run of the said study, designing of the stand, carrying out the measurements, presentation & analysis of the results, their transfer to the simulation medium, summarizing the results and presenting the conclusions provides to students of our Faculty a totality of practical skills required in the future professional activities of electronic engineers.

The Review of the Theoretical Framework

While speaking about wind power engineering, the wind power potential is usually analyzed; however, not the total power of moving air flow is technologically transferred into the power useful for the consumer.

In this analysis, wind is described as horizontal movement of air mass that is caused by the temperature difference on the surface of the Earth, because the Sun does not warm the surface of the Earth and the air of the atmosphere to the same extent. Cold air is heavier – in the atmosphere, it moves downward, thus forming high pressure zones. Warm air is easier, and it moves upwards in the atmosphere, thus forming low pressure zones. Air moves from a high-pressure zone to a low-pressure zone until the pressures become the same. Although wind is identified a renewable source of energy, it (because of its origin) is a phenomenon formed by the solar radiation. On analyzing the vertical section of the atmosphere, winds are divided to geostrophic winds and surface winds (Kytra, 2006). A geostrophic wind is formed on the height over 1 km; a wind formed on a lower height is a surface wind. In a layer of a surface wind, a zone of wind with the height up to 100 m may be found, because movement of air masses in the said zone is strongly affected by the roughness of the surface, i.e. inequalities of the surface of the Earth, buildings, plantations et cetera. It is natural that obstacles reduce the speed of the wind, so a higher speed of wind is observed in open territories, over oceans and seas. Close to obstacles, the windward and downwind zones are observed; they express themselves by the wind turbulence and its speed decrease.

The speed v is the key characteristic usable in wind power engineering analysis. According to the theory of classical mechanics, kinetic energy E of air flow (air mass) movement (Augulis, Jotautis, & Rutkuniene, 2012), shall be expressed as follows:

$$E = \frac{1}{2} m v^2 ; \tag{1}$$

here: v – the wind speed, m/s;
m – the air mass, kg.

The air mass moving through the wind wheel can be expressed as follows (Boyle, 2012):

$$m = \rho V = \rho A l = \rho A v t ; \tag{2}$$

here: ρ – air density, kg/m³;
V – air volume, m³;
A – area, m²;

l – length, m;
v – wind speed, m/s;
t – time, s.

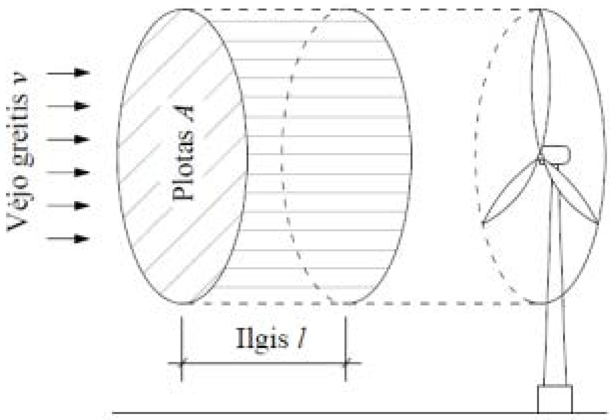

Figure 2 ***The Scheme of the Air Mass Moving through the Wind Wheel*** *(Boyle, 2012)*

So, the formula (1) may be expressed as follows (Mukund, 2006)

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(\rho Avt)v^2 = \frac{1}{2}\rho Atv^3 . \quad (3)$$

Power P of air mass or air flow shall be expressed as power change per time unit (Mukund, 2006):

$$P = \frac{E}{t} = \frac{\frac{1}{2}\rho Atv^3}{t} = \frac{1}{2}\rho Av^3 . \quad (4)$$

We can see from the formula (3) that the maximum theoretical power of wind stream directly depends on the third degree of the value of the wind speed, so the wind speed is a key parameter usable for establishing techno-economical characteristics of wind.

The primary technological equipment that contacts with the air flow is the wind wheel. The power P_{m_in}, i. e. the power obtained from the air flow per time unit, can be calculated according to the formula (1) upon taking into account that power obtained by the wind wheel from the air flow depends on the difference between the wind speed before the wind wheel (v) and the wind speed behind the wind wheel (v_0) (Mukund, 2006):

(5)

$$P_{m\_in} = \frac{1}{2}\frac{m}{t}\left(v^2 - v_0^2\right) = \frac{1}{2}G\left(v^2 - v_0^2\right);$$

here: v – the wind speed before the wind wheel, m/s;
v0 – the wind speed behind the wind wheel, m/s;

G – the mass air flow, kg/s.

According to the formula (2), the mass air flow G may be expressed as an arithmetical average of the wind speed before the wind wheel and the wind speed behind the wind wheel (Mukund, 2006):

$$G = \rho A \frac{v + v_0}{2}; \tag{6}$$

then:

$$P_{m\_in} = \frac{1}{2}\left(\rho A \frac{v + v_0}{2}\right) \cdot \left(v^2 - v_0^2\right) = \frac{1}{2} \rho A v^3 \frac{\left(1 + \frac{v_0}{v}\right) \cdot \left(1 - \left(\frac{v_0}{v}\right)^2\right)}{2}. \tag{7}$$

The last member in the formula (7) singles out the ratio between the wind speed before the wind wheel and the wind speed behind the wind wheel, thus describing the property of the wind wheel to adopt useful kinetic wind energy, and this non-dimensional value is referred to as the efficiency of the wind wheel, or the wind wheel's power factor c_p:

$$c_p = \frac{\left(1 + \frac{v_0}{v}\right) \cdot \left(1 - \left(\frac{v_0}{v}\right)^2\right)}{2}; \tag{8}$$

then:

$$P_{m\_in} = \frac{1}{2} \rho A v^3 c_p. \tag{9}$$

The maximum power factor cp of an ideal wind wheel equals to 0.593 and takes place when the wind speed behind the wind wheel is suspended upon the ratio 2/3, as compared to the wind speed before the wind wheel. This law was formulated and proved by German scientist Albert Betz in 1919. A. Betz published the results of his study in 1920 in the paper „Das Maximum der theoretisch möglichen Ausnützung des Windes durch Windmotoren“ („The theoretical limit of power of a wind turbine using the wind energy to the maximum extent”) (Betz, 1920), and since the said time, A. Betz's law has not been replaced or altered or proved otherwise A. Betz's law describes the maximum power transformation of a certain operating point; however, on operation of a wind turbine, other losses appear as well too.

Designs of wind wheels can be various; their technical propertied and the ones related to wind power transformation differ as well.

The Methodology of the Research

As it was mentioned above, designs of wind wheels vary, and our team had chosen one of them - the version of a turbine (Fig. 1). As a stand for tests, we can use an elementary analogue of a wind tunnel. The wind flow is generated by a fan; on its way, a prototype of a turbine is placed; in addition, one air flow meter is placed before the turbine and the second air flow meter – at the air flow output. As it was mentioned earlier, we measure two parameters: the starting point when the turbine starts moving (rotating) and the torque developed by the rotating turbine in its internal cavity. Torque measurements can be carried out on a gradual increasing the load and observing the rotational speed of the turbine. Such a curve drawn for a constant air flow (that remains the same after a change of the turbine rotor configuration) would describe a turbine with a certain number of wings. For this purpose, we print rotors of different configurations (with different numbers of wings) and then carry out the measurements at a constant air flow upon varying the number of turbine wings.

The practical measurements seem to be simple; however, the restrictions applicable both to the process of studies and the practical training prevented us at present from presentation of the collected data and their analysis. For the same reason, the main question raised for this stage of the research remained unanswered: what number of wings is most efficient for such a turbine configuration. So, it was decided to present the computer simulation of the wind tunnel only. Because it also considerably affects the educational activities of the students and can be fully integrated in the process of education.

The simulations used Autodesk® CFD 7 (Autodesk CFD, 2021) software to turn a 3D CAD workstation into a fully interactive liquid and gas test bench, thermal test rig, or wind tunnel. 3D layouts become interactive, at no cost to prototypes, revealing critical engineering information that is difficult to obtain through physical testing. Change the design of the model and we will see the same change in Autodesk® CFD right away. This software has been used in combination with Autodesk Fusion 360 6 (Autodesk Fusion, 2021), which is 3D and 2D modeling software with a fairly user-friendly environment that allows you to use it comfortably without much challenge. It is a powerful program that allows you to create complex and large-scale layouts. Thanks to Fusion 360's ability to import layouts of required materials directly from the manufacturer's catalogs, it is possible to save time by designing less significant components (bolts, nuts, profiles, etc.) and use that time to implement the basic layout. Also, the ability to simulate moving parts of the device (albeit limited) allows for a better understanding of the performance, durability of the final layout, and the anticipation and improvement of potential engineering mismatches.

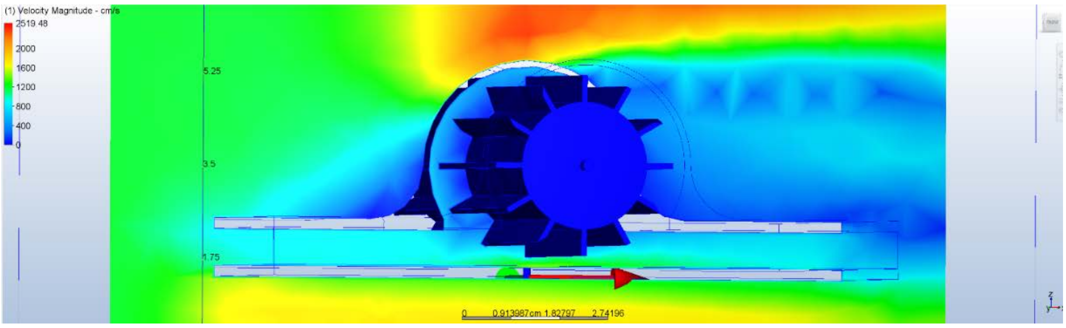

Figure 3 ***The Turbine in the Wind Tunnel Simulation***

The initial situation of the wind tunnel is presented in Fig.3 above. The chosen design of the wind turbine appeared to be not very effective. As one can see from the image of the simulation, a very weak air flow moves through the turbine wings and our goal is to achieve the maximum possible efficiency. The colored scale in the left part of the Figure indicates the intensity of the air flow in colors. The colored distribution presented in the Figure shows where air flows are most intensive. So, it can be presumed that an improvement of the design of the turbine body upon preserving the existing chosen geometry of the turbine is required.

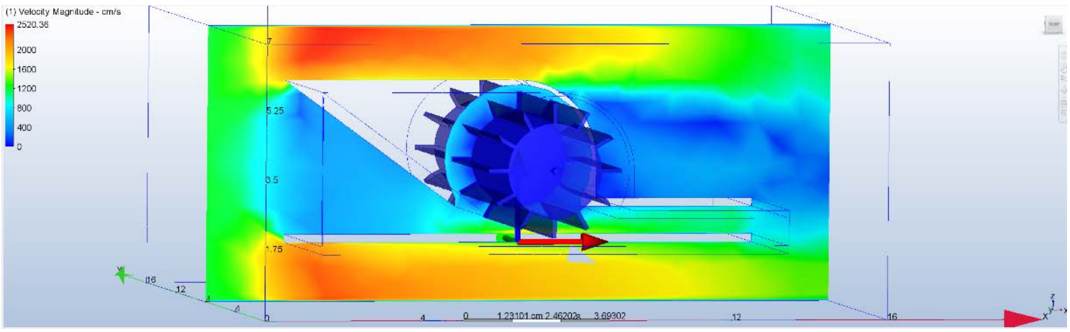

Figure 4 ***The Corrected Turbine in the Wind Tunnel Simulation***

It was decided to broaden the air inlet and to repeat a simulation once more. The repeated simulation is presented in Fig.4 above; it can be seen, that now, the intensity of the air flow through the wings grows considerably.

In such a way, step by step, we plan to fix coherently the maximum efficiency on each phase of the study and – after integrated coordination and summation of all phases – we hope to obtain a practically applicable electric generator for electric cars that enables to increase the distance coverable by a car after a single charging its battery at a stationary charging station. As it was mentioned earlier, an electric car may be considered a certain autonomic robotic system, so in a broader sense it is the first step towards creation of a generator for autonomic robotic systems.

In such a way, the methodology of the study, applicable methods and the strategy of the run of the experimental research chosen by our team can be defined.

The Results of the Study and the Conclusions

The result of this first phase of the study is an obvious improvement of the turbine body upon applying the results of computer simulation only. However, it is only a technical achievement. In summary, the very important social role of this phase in the training process is that the youth starts taking an interest in research activities and practical application of technological solutions important for the total community that guide towards environmental conservation and protection as well as care about each other. It will help our new generation, in addition to developing the sense of social responsibility and understanding, to observe and adopt the inevitability of integrity. In the higher education process, integration of such studies is undoubtedly a very useful and promising tool.

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