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As to selection of best design values for wind-driven wheel of rail-track-adjacent electric power plant

***Abstract**. This article substantiates and offers the procedure for selecting the best design values for a wind-driven vertical-axis wheel of a windmill electric power plant to be installed close to a rail track and to be used for conversion of the power of wind flows created by running railway trains into electrical power.*

Streszczenie.** W artykule opisano project horyzontalnego napędu wiatraka użytego do wytwarzania energii. Wiatrak umieszczony jest w pobliżu toru kolkejowego i wytwarzany przez kolej ped powietrza wykorzystuje się do generacji energii elektrycznej. **Projekt wiatraka wykorzystującego ped powietrza wytwarzany przez pojazdy kolejowe

Keywords: wind power, railway train, rail track, vertical-axis wheel, windmill electric power plant.
Słowa kluczowe: energia wiatrowa, kolej, waitrak horyzontalny

Introduction

It is well known [1, 2], that the power P_{wf} (W), which is derived from a wind flow having the density ρ (kg/m^3) by a vertical-axis wind-driven wheel of the axial area of S_w (m^2) is proportional to such area and to the velocity cube v_{wf} (m/sec) of such wind flow, so it can be expressed in terms of the following relation:

$$P_{wf} = \varepsilon \cdot (S_w / 2) \cdot \rho \cdot v_{wf}^3 \tag{1}$$

where ε is the wind power conversion factor, the value of which depends on the wind wheel design, in particular, on the degree of occupancy of the wheel space by the blades thereof, as well as on the specific speed thereof.

Any body moving in gas or liquid creates trailing and sidelong turbulent flows of such liquid or gas. Likewise, a running railway train creates fairly strong wind flows, depending on its shape and speed, in front and around it. Notably strong wind flows are created by running freight trains by virtue of aerodynamic imbalance of loaded wagons. This can be felt by anyone standing on a landing place when a freight train is passing by a railway station without stopping there. So, it would be wise to convert the power of wind flows, produced by passing railway trains, into electrical power which can be used both for autonomous energizing of railway ancillary systems and for enhancing the reliability of the existing power supply systems for such ancillary equipment, which is further detailed in the work [3].

In the work [4], we suggest creating special wind-driven electric power plants (WDEPPs) and set the conditions for location thereof along railway tracks for converting the power of wind flows, caused by running railway trains, into electrical power to be used for energizing any railway ancillary equipment, or for such energy recuperation or accumulation.

In the work [5], we have made a quantitative assessment of the power of wind flows created by running railway trains, using, however, the American Railway Association's data delivered in the work [6]. In order to verify the results of the said assessment and to adapt them to the Ukrainian specifics of railway transport management and operation, we have carried out an experiment on ascertaining the parameters of the wind flows, as created by railway trains, which are detailed in the work [7], while the measuring equipment used in the said experiment is described in the work [8].

The aim of this article is to substantiate and develop the procedure for selecting the best design values for a wind-driven vertical-axis wheel of a wind electric power plant to be installed close to a rail track and to be used for conversion of the power of wind flows, created by running railway trains, into electrical power.

Solution to the problem set

Let us start solving the problem, as set herein, with determining the effective diameter of a wind-driven wheel.

As is shown in the work [9], such an important physical parameter of a wind flow as Reynolds number (Re) is associated with the air-stream velocity v (m/sec) and with the chord b of the vertical blade of the wheel within the circular cross-section of such wheel as shown in the relation below

$$\mathrm{Re} = 68500 \cdot v \cdot b \tag{2}$$

which can be used for determining such a parameter of a wind-driven wheel as the length of the blade chord b.

However, at first we will present another result of the work [9], i.e. the graphs, as shown in Fig. 1, which demonstrate the interrelation between Reynolds number, the lifting force occurring on the blade under air stream and the motion drag thereof.

It is clear from Fig. 1 that to ensure efficient performance of a wind-driven wheel, it is necessary to select Reynolds number from among the values belonging to the supercritical range, where the lower limit is $\mathrm{Re} = 80000$. So, this lower limit of Reynolds number is the threshold where we start from, having somewhat increased such limit value in order to guarantee proper performance in the said supercritical range, for instance, 85625. Having substituted Re for 85625 in the relation (2) above, we arrive at

$$85625 = 68500 \cdot v \cdot b \tag{3}$$

As is well known, the often lowest cut-in wind flow velocity, which can drive a wind-driven speed, is $v = 5\ (\mathrm{m/s})$. So, having inserted such value in the relation (3) above, we find that

$$b = 85625 / (68500 \cdot v) = 85625 / (68500 \cdot 5) = 0.25\ (\mathrm{m}) \tag{4}$$

Based on the graphs, as shown in Fig. 1, and on the expression (4) above, it is possible to assert that a wind-driven wheel with a blade chord of 0.25 (m) will respond not only to wind flows, created by railway trains, but also to natural wind blowing at the time when no railway train is passing by, unless the velocity of such natural wind is less than 5 (m/sec).

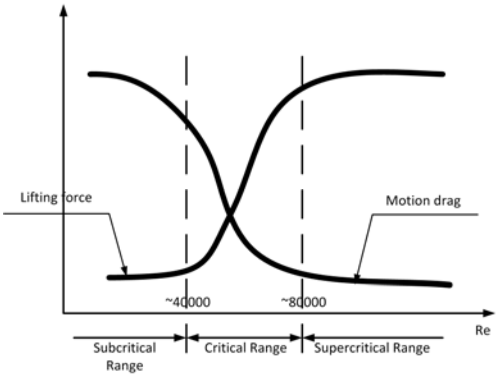

Fig.1. Graphs of lifting force acting on wind-driven wheel and blade motion drag versus Reynolds number

Having got the blade chord length value b and having assumed that a wind-driven wheel has 3 blades, we can determine the diameter D of such wind-driven wheel, using the expression below

(5) $$D = 3b/k$$

taken from the work [9], where k is the wind-driven wheel effective space blade-occupancy factor.

Having admitted that $k = 0.3$ and having inserted this k value together with the b value, derived from the relation (4), in the relation (5), we find that $D = 2.5\,(\mathrm{m})$.

However, such wind-driven wheel diameter value is not acceptable because our experiment, as described and computed in the works [7,8], demonstrates that the power elements of a wind flow, generated by a running railway train, are distributed among the quadrants in the plane perpendicular to the train axis as follows.

(6) $$\begin{pmatrix} 5.951 & 6.619 & 5.576 \\ 13.004 & 7.32 & 7.471 \\ 20.448 & 10.502 & 2.577 \\ 9.006 & 8.713 & 2.815 \end{pmatrix}$$

See the graphical interpretation of the matrix-like expression (6) in Fig. 2.

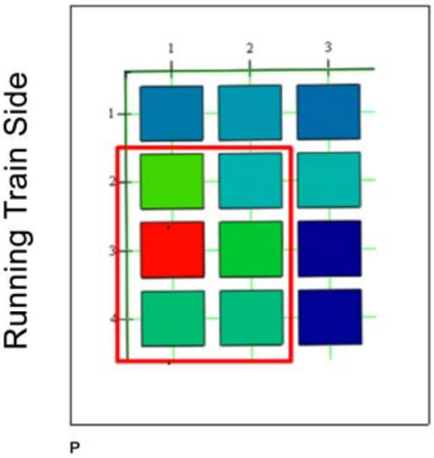

Fig.2. Graphical interpretation of train-induced wind flow power allocation with highlighted maximum power areas

As it is seen from Fig. 2 and from the expression (6) above, around 70% power of a wind flow created by a running railway train falls within the area bounded by a red rectangle, the vertical side of which ranges within $2.25 \div 2.8\,(\mathrm{m})$, depending on the surface smoothness of the wagons, and the horizontal side within $1.1 \div 1.5\,(\mathrm{m})$; this correlates with the results, which have been obtained in the work [10]. So, it makes no sense to set the diameter of a wind-driven wheel as large as 2.5 (m).

However, according to the expression (5), the wind-driven wheel diameter D can fall within the range of $1.1 \div 1.5\,(\mathrm{m})$ only on condition that the k factor be doubled. This can be achieved through an increased number of blades and, respectively, reduced speed of a wind-driven wheel. If $k = 0.6$, then, using the expression (5), we find that $D = 1.25\,(\mathrm{m})$. To improve the startability, we suggest using dual blades, in our case, blades with the chord of 0.125 (m) each instead of a single blade of 0.25 (m). A preceding blade is a vortex generator for a subsequent one, thereby increasing the lifting force factor and widening the range of angles of operating incidence. This contributes to a higher efficiency of flow energy conversion while reducing the speed of the wind-driven wheel. Furthermore, if we make a double-row wheel, as is offered in the work [11] and shown in Fig. 3 and Fig. 4, and if we shift, along the central rim of the wind-driven wheel, the blades of the upper row against the lower row blades by 60°, we will achieve better torque smoothness.

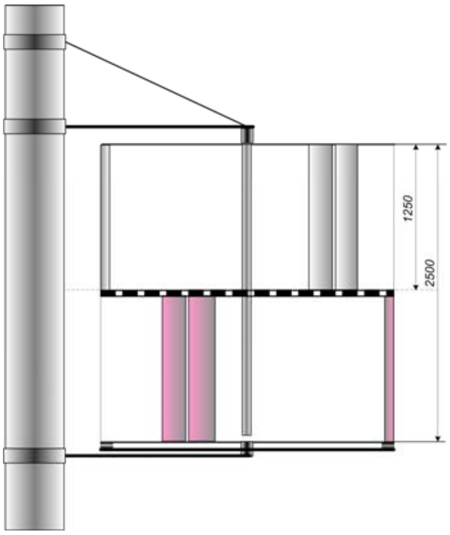

Fig.3. Design of wind-driven wheel for deriving energy from wind flows generated by railway trains passing by. Side view

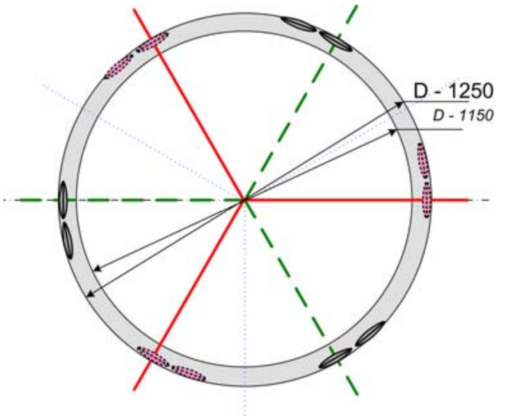

Fig.4. Cross-sectional view of double-row wind-driven wheel cut with a plane passing through the central rim, where the solid lines show the chords of one row, while the dashed lines show the chords of the other row

Finally, we have to determine the last remaining parameter of a wind-driven wheel, i.e. its height h. To do so, we have to return to the expression (6) and to the graphical interpretation thereof in Fig. 2. As we have stated above, across the height of the wind flow cross-section, cut with a plane perpendicular to the rail track axis, most of the wind flow power is concentrated within the range of $2.25 \div 2.8\,(\mathrm{m})$. In consideration of the fact that we have chosen the wind-driven wheel diameter to be 1.25 (m) and that we have suggested that a wind-driven wheel be made double-staged, it makes sense to choose the height h for a wind-driven wheel from among the values within the range of $2.25 \div 2.8\,(\mathrm{m})$, as is acceptable in terms of the wind flow useful efficiency criterion, and to set it equal to $h = 2.5\,(\mathrm{m})$. As a result of such solution, we have a wind-driven wheel consisting of two rows, each sized $1.25 \times 1.25\,(\mathrm{m})$, both being interchangeable and complementary, which would simplify mounting of such wheels in the process of installation of rail-track-adjacent windmill electric power plants.

Given such dimensions, the area of the axial cross-section S_w of a wind-driven wheel is as follows:

$$S_w = D \cdot h = 1.25 \cdot 2.5 = 3.125\,(\mathrm{m}^2) \tag{7}$$

Having inserted the values below in the relation (1):

$$\begin{cases} \rho = 1.293\,(\mathrm{kg/m^3}); \\ \varepsilon = 0.4; \\ k = 0.6; \\ S_w = 3.125\,(\mathrm{m}^2) \end{cases} \tag{8}$$

and $v_{wf} = 5\,(\mathrm{m/sec})$, we find out that even when no railway train is passing by a wind-driven wheel, such wheel can derive the energy from the natural wind to generate the power equal to

$$P_{wf} = 0.4 \cdot (1.293/2) \cdot 3.125 \cdot 5^3 = 101\,(\mathrm{W}) \approx 0.1\,(\mathrm{kW}) \tag{9}$$

and, again, having inserted, in the relation (1), the values of the parameters from the expression (8) and $v = 15\,(\mathrm{m/sec})$, we find that when a railway train is passing by a wind-driven wheel, such wheel can derive the energy from the wind flow created by such train to generate the power equal to

$$\begin{aligned} P_{wf} &= 0.4 \cdot (1.293/2) \cdot 3.125 \cdot 15^3 = \\ &= 2727\,(\mathrm{W}) \approx 2.7\,(\mathrm{kW}) \end{aligned} \tag{10}$$

Having compared the expressions (9) and (10), we can see that the power derived by a wind-driven wheel from a wind flow produced by a railway train passing by such wheel is 27 times higher than that yielded by such wheel when no train is passing by.

Conclusion

1. This work has substantiated and offered the procedure for selecting the best design values for a blade chord, as well as for the diameter and height of a wind-driven vertical-axis wheel for a windmill electric power plant to be installed close to a rail track and to be used for conversion of the power of wind flows, created by running railway trains, into electrical power.

2. It has been demonstrated that the size of a wind-driven wheel blade chord should be selected based on Reynolds number value belonging to the supercritical range, while the diameter and height of a wind-driven wheel should be selected proceeding from the area which ensures the maximum retrieval of the power of the wind flow created by a running railway train.

3. Specific values have been obtained for major design parameters of a wind-driven wheel fit for use in a rail-track-adjacent windmill electric power station.

4. It has been shown how many times the power generated by a wind-driven wheel, impelled by a running railway train, exceeds the power derived by such wind-driven wheel when train is passing by.

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