What makes a wind-machine with pneumatic power transmission better than a conventional one?

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Abstract

The goal of the development described here is to improve Andreau-type wind-machine with pneumatic power transmission and to increase the power factor. In the middle of the twentieth century a 10 kW pilot wind-machine was built with such construction. According to measurement results the new machine was worse than the wind-machines with conventional mechanical power transmission therefore the pneumatic power transmission was turned down without attempting to improve it. We make up for what was missed and hope that we will built a wind-machine with pneumatic power transmission which is better than those being used today. We elaborated several intentions then a patent therefrom. We built a pilot wind-machine. We constructed a closed wind turbine to examine suction elements and an open wind turbine to test internal wind turbine. We carried out measurements with these tunnels and found the results hopeful for the future therefore we intend to continue this development.

In wind-machines with pneumatic power transmission a large part of the blade is similar to the conventional one, these parts rotate the air that moves away from the wind turbine in the same way as in the conventional one but here we can exert influence on the rotation of the air by altering the direction of the air jet moving away from the suction element.

Inside the pneumatic wind-machine air is moved by an air jet pump operated at the outlet. It is a fact that the high speed air jet, while moving away, takes away a lot of kinetic energy. In the unfavourable case the air jet moving away from the suction element, like the other parts of the blade, rotates the air in the direction opposite to the turbine therefore the losses are added together.

In the favourable case, when the suction element is transformed to a ventilator blade, the air jet moving away from here rotates in the same direction as the turbine, and the two air masses rotating in opposite directions are mixed together, and the rotation decelerates or stops, and the most part of the energy lost in the rotation of air is being utilized.

Figure 1: Andreau-type wind-machine

Key words

wind-machine, windmill, pneumatic power transmission, loss, Betz's law, power factor, pilot wind-machine, tip speed ratio, wind tunnel, air jet pump, wind turbine, pneumatic output
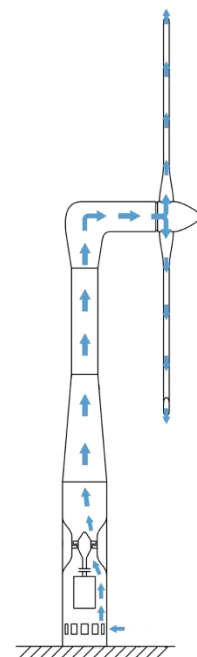
Introduction

More than sixty years ago, based on the patent of M. Andreau, a 100 kW test wind-machine was built in Southern England with pneumatic power transmission. An article [1] published in *Engineering* in March 1955 describes the machine and the experience gained therefrom (**Hiba! A hivatkozási forrás nem található.** 1).

In conventional wind-machines used to generate power the wind turbine turns a generator through a mechanical coupling. In wind-machines with pneumatic power transmission the turbine rotates freely. Turbine blades, the head and the column form a closed continuous duct. The duct starts from the air intake openings located at the bottom of the column and ends in the air outlets rearward facing the end of the blades (Figure 2). An air turbine is located in the duct and a generator is connected thereto. When the wind turns the turbine, the air flowing beside the outlets sucks the air out of them. This suction moves the air in the duct and the air flowing inside turns the turbine and the turbine drives the generator.

The velocity of the wind and power output were measured during operation of the machine. It was found that the power factor of the wind-machine was 14.5%, i.e. the machine utilized such proportion of the capacity of the wind. In those days the power factor of conventional machines that have been developed for decades reached approx. 30%. By this token, the pneumatic system was turned down.

To answer the question raised in the title, I give a list of reasons then I will go into the details:

1. The Andreau-type wind-machine with pneumatic power transmission built, tested and rejected in the past was better than it was considered. I think adversely selected testing conditions also contributed to poor test results that led to a wrong decision and rejection.

2. I have elaborated two patents which reduce loss of flow on external and internal surfaces of blades., where

   The first patent, by increasing intensity of the suction, reduces the volume of air required for power transmission and, as a result, the velocity of the air flowing inside,

   The second patent, by decreasing cross-section of the external end of the blade, increases the cross-section of the hollow blade and reduces its length, and with these modifications the flow resistance of the blade drops considerably.

3. To intensify suction, the air flowing in front of the outlet is accelerated. The energy used for acceleration will slow down the turbine but it is not a problem because by adjusting braking to the correct degree we can ensure that the turbine produces maximum power at every wind speed. Selecting proper flow direction for the air leaving the duct most part of the energy used to intensify suction can be recovered.

4. The force acting on the blade from wind direction is reduced because here the central section of the blade, or suction element, becomes a fan blade and an opposite direction force acts on its surface, compared with other parts of the blade. Accordingly, the head and column of the wind-machine are subjected to a force equal to the difference between the two forces.

5. The monotonous noise on account of which large wind-machines should be installed at a minimum distance from residential areas is eliminated. The noise is generated when the blade of the machine operated in a high-speed win is passing in front of the column and the air accelerated in the vicinity of the blade comes up against the column. The turbine of the pneumatic wind-machine is always behind the column and here there is nothing with which the accelerated air flow could collide.

6. Pneumatic wind-machines are able to start and stand into wind direction without any external energy, network or accumulator and to utilize so slow winds by which conventional wind-machines cannot even be started.

7. In the pneumatic wind-machines there will be no multiplying gear or complicated devices to stand the blade into wind direction and to adjust blade angle, resulting in lower operating and maintenance costs, and the service life of the machine is increased several times higher and the cost of power generation is reduced significantly.

Details

In conventional wind-machines with mechanical or pneumatic power transmissions friction between solid surfaces and air resistance are major sources of losses. These, however, exert effects of different magnitudes. In wind-machines with large driving units friction is determinant, while in pneumatic wind-machines air resistance is the key factor. The difference between the two types of machines is caused by the fact that the coefficient of friction is constant and its level does not change with the velocity of movement, while air resistance increases proportionally to the square of the wind speed. Figure 3 shows estimated losses of the two types of machines versus wind speed.

The diagram reveals that at low wind speed, before the point of intersection of the two curves, the loss is lower in the pneumatic machine and higher in the wind-machine with mechanical power transmission when the wind speed is high. The extent of friction loss is demonstrated by the fact that large conventional machines can only be started when the speed of the wind exceeds 5m/s, because at this speed net power obtained from the wind exceeds losses. In contrast, our pneumatic test machine started at a wind speed as low as 1m/s and reached a measurable output at a wind speed of 2m/s. It is true that the output that can be achieved at wind speeds of less than 5m/s is low but at places with continental prevailing winds 20% of total energy is frequently generated under these circumstances. On the other hand, a drawback of the pneumatic machine is that above a certain wind speed the loss of flow is so high that net output will not increase with stronger winds. One of the goals of the development is to increase this limit velocity.

After getting acquainted with Andreau-type pneumatic wind-machines, many decades ago, I decided to try to improve it. My first assumption was that one of the causes of poor performance was the rearward facing outlet at the end of the blade which was a low performance suction device (Figure 2 2).
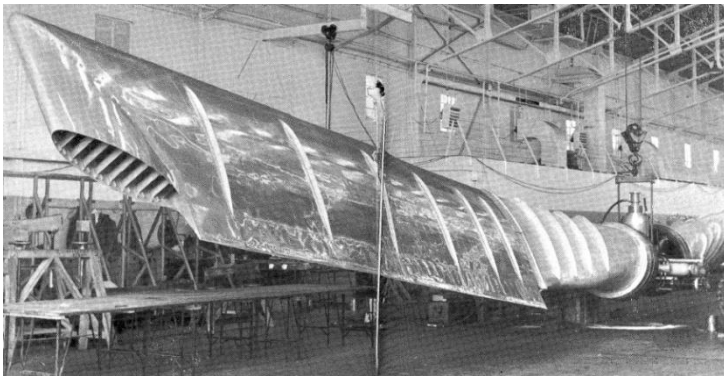

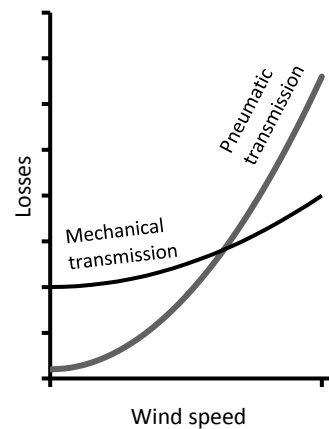Figure 2: the blade of the Andreau-type wind-machine with the air outlet

Figure 3: change in losses versus wind speed

To eliminate this deficiency I applied for a patent titled "Wind-machine with pneumatic power transmission", whose reference number is HU/P 0103756 and its registration number is 224 256. In this patent I presented constructions which produce a larger pressure difference between internal and external spaces than the rearward facing outlet.

In order to test one of the constructions described in the patent we built a four-bladed pilot wind-machine with a diameter of two meters. The machine can be seen from afar in Figure 4 and Figure 5 shows the wind turbine from a short distance. The two photos were taken from different positions. Figure 6 illustrates one blade of the turbine from two different views, while Figure 7 shows a perspective view thereof.

Figure 4: the wind-machine from afar

Figure 5: the air turbine from a short distance

This blade is composed of two sections. The first section connected to the hub of the turbine is similar to the blade of the conventional high speed wind turbine, considering that it is also a twisted blade and has an aerofoil cross-section, while the difference is that it has a larger cross-section so that the resistance of the duct hidden in the blade is kept as low as possible. The other section of the blade is the suction element connected to the first section, and it also has an aerofoil cross-section and hollow profile with a convex shape and there is an air outlet on its rear side. There is a lentiform element between the two sections of the blade so that the position of the section element, compared to the ducted blade, can be changed. The effectiveness of the new suction element is demonstrated by the fact that a much lower peripheral speed is sufficient to create the necessary pressure difference than required for the former outlet. The tip speed ratio is equal to the quotient of the peripheral speed and wind speed. The tip speed ratio of the Andreau-type pilot machine was 9.5 and we achieved 5. Reduction of the tip speed ratio is beneficial because the loss of flow arising on the external surface of the blade and the noise can be reduced this way.
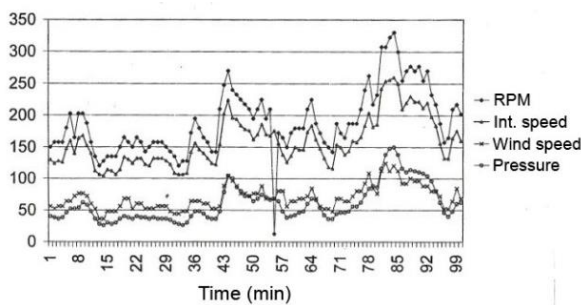

Diagram 1: The results of mesurements conducted at the same time are proprtional to each other (are well collerated).
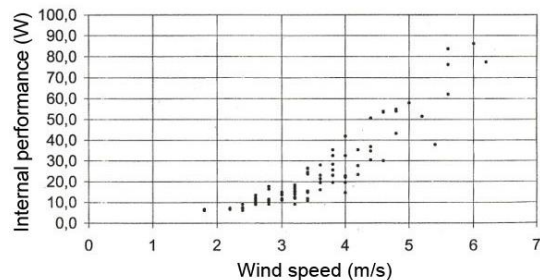

Diagram 2: Internal pneumatic performance versus wind speed

We built the pilot wind-machine so that we can measure the usefulness of the modification, i.e. the kinetic energy of the air flowing inside should have been converted to electricity or, at least, mechanical energy. We, however, have not found an air turbine suitable for this purpose therefore we calculated pneumatic performance from mass flow and pressure difference. For this measurement we used dummy load, an orifice with alterable cross-section. Similarly to the

Andreau-type pilot wind-machine, the wind turbine of our pilot wind-machine was also behind the column, where the wind pressure exerted on the turbine turned it. We fixed the wind speed meter to the top of the engine room, as far from the turbine as possible. During the tests we measured the wind speed, the RPM of the turbine, the amount of air flowing inside and the pressure difference between the internal and external spaces every two seconds.
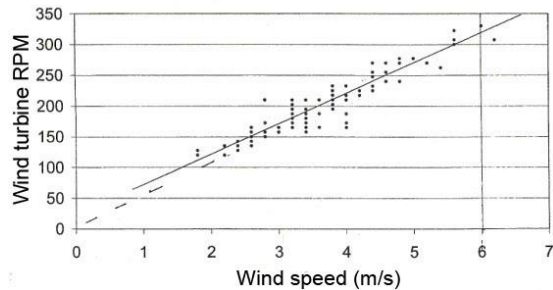

Diagram 3: RPM of the wind turbine versus wind speed. The tip speed ratio is equal to approx. 5 but not constant; it decreases slowly as the wind speed grows.
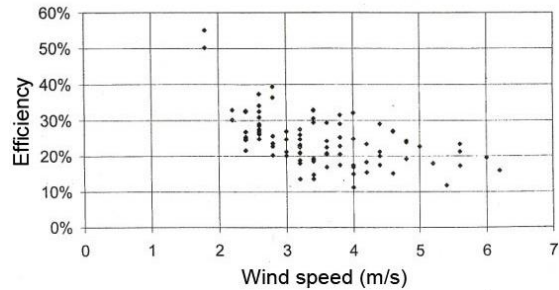
Diagram 4: Efficiency versus wind speed, it drops rapidly as the wind speed grows

Within each measurement series we kept the throttle that loads the flow, i.e. a diaphragm, at constant size. We present diagrams edited from data of a single series under numbers 1, 2, 3 and 4.

A spectacular result of this measurement series was a rapid decrease in power factor with an increase in wind speed. In my opinion, one of the causes of the failure was that, due to our financial capabilities, the linear dimension of our machine was ten times smaller than the previous machine (size effect), and another cause was that we selected a very small cross-section for our blade.

A number of obstacles hindered outdoor measurements therefore we continued the development process in a lab.

We constructed a closed wind tunnel (Figure 9) to examine suction elements. We conducted a lot of measurements in the tunnel and found that we could multiply the effect of the suction element with an aerofoil cross-section compared to the first measurement. In the example presented in this article we increased the suction intensity so that we turned the suction element to a position similar to a fan blade. More exactly, the suction element was positioned in the same manner as the centre of the propeller stands when the airplane already flies at high speed. In the second invention we present a different example to intensify the suction power.
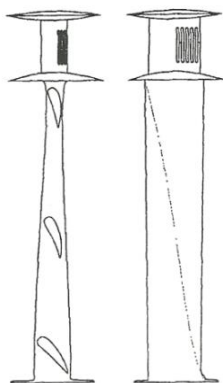

Figure 6   Figure 7   Figure 8

To convert kinetic energy of the air flowing inside we prepared an air turbine. The air turbine and the open wind tunnel constructed to test the turbine are shown in Figure 10.

Figure 9: Closed wind tunnel

Figure 10: Open wind tunnel

The second invention is based on the recognition that the blade of the wind turbine is the critical element for the wind-machine with pneumatic power transmission. The problem is that here the blade has to fulfil two functions. The first conventional function is to rotate the turbine, and the second new function is to lead the air flowing in the machine from the hub of turbine to the suction element. To fulfil the first function effectively a narrow blade similar to the blades of conventional wind-machines should be used here too, but in this blade there is hardly room for the duct. To fulfil the second function properly a blade with large cross-section should be used, but at high wind speed a high loss of speed would arise on its external surface.

To solve this problem we elaborated the second invention titled: Wind turbine for wind-machines with pneumatic power transmission. Date of application: 14 December 2012, reference number: P1200735. Reference number of the international application: PCT / HU 2013000124.

One version of the blade claimed in the invention is shown in Figure 11.
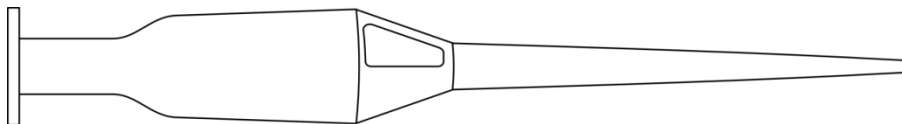

Figure 11: Wind turbine blade composed of three sections

The essence of the invention is that the blade is composed of three sections: The first section has a hollow profile and large cross-section and is connected to the hub of the turbine. The second section is a hollow suction element with an air outlet. The third section is the ductless external end of a conventional high speed wind turbine blade with small cross-section. At high wind speed the loss of flow arising on such a blade makes up only a few percent of that arising on our blade illustrated in Figures 2, 6 and 7.
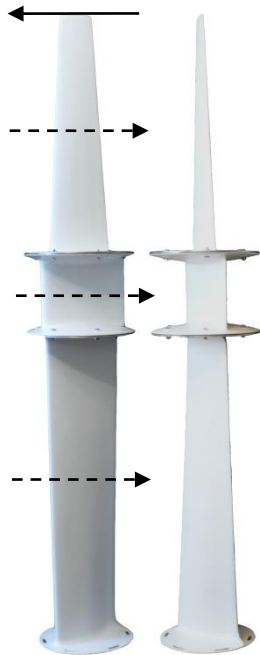
Figure 12   Figure 13

Figure 13   Figure 14

We have recently prepared the third section of the blade that had been composed of two sections so far, i.e. the slender ductless end of blade. The first two sections can be assembled in two ways. The first method can be seen in Figures 6 and 7. In this case the second section, i.e. the suction element, is connected to the first section as if it was a continuation thereof. We performed the previous measurements using such a blade. The second method to fit together the two sections is illustrated in Figure 8. In this case the second section, the suction element, stands as if it was a short part of a fan blade. In both cases the third section should be fixed to the suction element as if the third section was a continuation of the first section.

Figures 12 and 13 show the blade assembled according to the first method and supplemented with the third section when the blade is in its upper vertical position. Figure 12 is an axial view. In this figure we have also illustrated directions of movements. The movement of the blade is shown by a continuous line with an arrow, while dotted lines with arrows indicate the path of the air moving away from the three sections of the blade. Figure 13 shows a tangential view of the blade moving away. In Figure 12 three dotted arrows illustrates that air leaves all three sections of the blade in the direction opposite to the blade. Nevertheless, by rotating the air more energy is lost than in the conventional wind-machine with mechanical power transmission, because more air moves away from the second section, i.e. the suction element, at higher speed than from the blade of a conventional wind-machine of the same length.
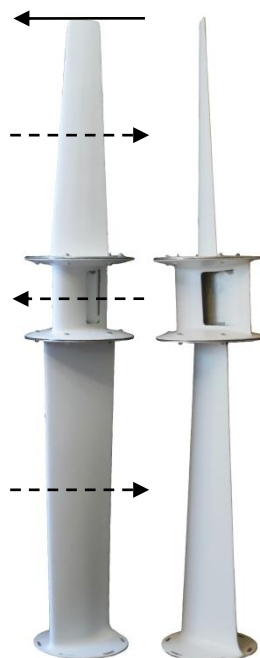
The good solution, the blade assembled according to the second method and supplemented with the third section is presented in two views in Figures 14 and 15 when the blade is in its upper vertical position. Directions of movements are shown in Figure 14 as well. The continuous line with an arrow shows once again that the blade rotates anticlockwise. The dotted lines with arrows indicate the direction of the movement of the air moving away from the three sections of the blade. The air moving away from the first and third sections of the blade rotates clockwise. On the other hand, the air moving away from the second section of the blade, the suction element, rotates anticlockwise like the turbine blade. However, the air masses moving away from the three sections of the blade not only rotate but move in wind direction and the air jet moving away from the second even picks up speed. Shortly after leaving the blade the air masses mix together and their rotation slows down or stops and the rotational kinetic energy that has been useless so far is being utilized.

About wind energy

Before analysing effects of various blades, let us examine briefly how much energy is in the wind, how much of this energy can be utilized and where is the missing part lost.

Wind energy is the kinetic energy of flowing air. Its amount is equal to the product of the mass of the air and the second power of its velocity. The wind power is equal to the product of the mass and the third power of the velocity.

The reason why large equipment should be built for the utilization of wind energy is the low density of the air. The mass of one cubic meter of air is roughly 1.3 kg/m^3 which varies with temperature and barometric pressure. For your information we present a few power data:

Wind speed [km/h]	3.6	7.2	11	18	36
Wind speed [m/s]	1	2	3	5	10
Specific power [W/m^2]	0.647	5.2	17	81	647

More than ninety years ago Betz demonstrated with calculations that maximum 16/27 or approximately 59% of the kinetic energy of the wind can be extracted. 11/27 of the energy is needed to pass the decelerated air. Power factor is the ratio of power extracted from the wind and the total power contained in the wind, expressed as a percentage (this definition is similar to efficiency). The power factor of the best wind-machines that have been built so far is around 40%. The missing 19% as a loss is not justified by the construction of the well-known machines therefore we have to find the way where energy is lost.

In the past decade the Technical University of Budapest published a book [2] which states „*While passing the plane of rotation axial velocity of the air flow declines and suffers a tangential deflection as well (in the opposite direction to the direction of rotation of the rotor).*" The author has not mentioned it but I interpret this sentence so that some part of 19% that is missing from the energy that can be utilized according to Betz is lost here in kinetic energy of the rotation of the mass of air moving away. A couple of years ago I saw a short video where the air moving away from the turbine was spinning in the direction opposite to the movement of the wind turbine.

According to Betz's law, no turbine can capture more than 16/27 of the kinetic energy in wind, and 11/27 of the energy should remain in the decelerated air to continue its motion. The wind turbine makes use of the linear energy by converting it to rotational kinetic energy. It seems, however, that two rotations arise at the wind turbine. The turbine rotates both its own shaft and the air passing between the blades in the direction opposite to the turbine. Based on the action/reaction principle we have reason to assume that the two energies converted to rotation have the same intensity. In fact, we can convert only one half of 16/27, which has been deemed usable so far, to mechanical then electrical energy, while the "benefit" of the other half is that the air is rotating, but it is a loss as well. In my opinion, this assumption does not conflict with Betz's law, perhaps makes it complete. To disprove or accept this assumption the energy disappearing by the rotation of the air that moves away from the turbine should be measured and added to the energy balance.

In the wind-machine with pneumatic power transmission a large part of the blade is similar to the conventional one, these parts rotate the air that moves away from the wind turbine in the same way as in the conventional one, but here we can exert influence on the rotation of the air by altering the direction of the air jet moving away from the suction element.

Effects of blades that has been constructed and tested so far

Blades shown in Figures 2, 6 and 7 had been manufactured and produced a poor power factor. The cause of the poor result was presumably that the air jet pump running at the ends of the blades is an inefficient device. It makes use of perhaps one half of the energy obtained from the air to move the air flowing in the duct. The other half of the energy is included in the kinetic energy of the air having been sucked and the air that exhausts the sucking air. Since this air jet

spins also in the direction opposite to the rotation of the turbine, the loss arising here is added to the kinetic energy of the spinning air mass moving away from the other part of the blade.

Expected effects of blades to be tested

My next idea is to turn the suction element into the position shown in Figures 8, 14 and 15, and with this modification I transform it to an axial fan blade. I expect this modification to increase the speed of the air passing in front of the outlet and to further intensify suction. However, the suction element that has a shape of and is located as a fan blade not only increases suction capacity but gives a new direction to the air jet moving away from the suction orifice and reduces losses this way, since the fan blade drives the air in the wind direction and rotates it in the same direction as the turbine. This air jet moving away from the suction element is mixed with an air mass moving away from the other part of the blade and rotating in the opposite direction. This air jet decelerates the rotation and accelerates the movement of the air mass to utilize some part of the losses arising in the rotational movement. .

Accordingly, the reason why the wind-machine with pneumatic power transmission is better than the mechanical one is that one of the losses of the turbine, i.e. rotation of the air, is balanced or compensated by a similar loss of pneumatic power transmission, i.e. the air moving away from the air jet pump at high speed.

The fan blade rotates a small mass of air at high speed in the same direction as the wind turbine rotates. The other two sections of the blade rotate a larger mass of air in the opposite direction. With the size of the blade sections and the angle between these sections and the plane of rotation can and should be approached, or reached maybe, that the tangential components of the kinetic energy of the two rotations are equal and the rotation of the air moving away from the wind turbine is prevented.

In the development process the next task is to rebuild the pilot wind-machine stored in a dismantled state and to conduct a measurement series, similar to that described above, on the machine. However, I cannot continue and accomplish this task alone. In order to perform a lot of work involved I am looking for partners among those who deem my idea useful and feasible.

Budapest, 13 September 2016.

References

[1]   Wind-generated Electricity, *Engineering*, March 25, 1955

[2]   Mátyás Hunyár (2008) – Electrical machines and their control in renewable and environmentally friendly power engineering systems, Publisher of the Technical University, pp. 41.