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CONCEPT OF ACCUMULATION SYSTEM CONFIGURATION ENABLING THE USAGE OF LOW-POTENTIAL WIND ENERGY

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The construction concept will allow gaining the maximum value of aerodynamic effectiveness in a wide range of service conditions. In this way conceived wind aggregate will enable capturing the low-potential wind energy and its transformation and accumulation into electric energy usable as peak energy by the means of energetic converters with capacitance accumulation. Part of the solution is also a configuration concept of objective wind energetic unit with non-electric accumulation with trend to the possibility of a wide usage in the energetic network structures.

Key words: *wind energy, renewable energy sources, accumulation of energy, wind aggregate*

Koncept konfiguracije akumulacijskog sustava koji omogućava uporabu nisko potencijalne energije vjetra. Predloženi konstrukcijski koncept omogućiti će postizanje maksimalne aerodinamične učinkovitosti u širokom rasponu eksploatacijskih uvjeta. Pretpostavljen agregat na vjetar će omogućiti prikupljanje nisko potencijalne energije vjetra te akumulaciju i transformaciju te energije u električnu energiju, iskoristivu kao vršna energija, pomoću energetskih pretvarača i akumulatora. Dio predloženih rješenja je također konstrukcijski koncept energetske jedinice na vjetar s neelektričnom akumulacijom koja bi trebala naći široku uporabu u energetskim mrežnim strukturama.

Ključne riječi: *energija vjetra, obnovljivi izvori energije, akumulacija energije, vjetrov uređaj*

INTRODUCTION

In comparison with western-European countries, the Slovak Republic as an inland country disposes with considerably lower wind-energetic potential determined by weather conditions. The basic criterion for estimation of potential is the average wind velocity. Generally, the type of locality is considered according to the average wind velocity and the annual energy production can be determined referring to the air flow area unit which annually flows through the propeller diameter.

From the technical power-plant usage of wind energy the area of Slovakia belongs to a region with relatively low wind potential. This is caused by the fact, that the technology of electric power production by propeller wind power-stations is based on the usage of uniformly flowing wind with quasi constant velocity and flow direction. These capital expensive equipments reach nominal output in wind velocities in interval approximately 10 - 15 m/s. Only few high locations of the most exposed mountain ranges of Slovakia (2 % of the area) can satisfy these conditions.

The starting wind velocity for axial-flow wind power-stations with regulation stahl is approximately 3,5 to 5 m/s and for power-stations with regulation pitch, with generators working in wide range of revolutions, 2,5 up to 3,5 m/s. Wind aggregates with vertical revolution axis existing today, using the pressure principle are - in comparison with propeller aggregates - characterised by low service effectiveness and they are not used in electroenergetics.

SOLUTION CONCEPT

According to the above mentioned facts there arouse the need to develop wind equipment, concept of which will take into account more specifics, from the view of the character of the flow in the area of Slovakia, as well as from the view of the position in the electric network.

As the aim we have chosen to design a stable standpoint with sufficient storage tank of wind energy, possibly with storage tank of compressed air. Wind energy serves as the primary resource, when it powers the compressor, which fills the pneumatic accumulator (storage tank of compressed air).

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The compressed air is in the time of peak endurance consumed from the pneumatic accumulators for the work of pneumatic engine, which powers the generator and the produced electric energy is being supplied to the public network. In the time of insufficient output of wind energy the compressor is powered by classical energy resource. Wind energy serves as complementary resource for the compressor drive. At work we consider a pressure container with volume V = 10 000 l. In the necessary compressor concept we consider producing compressed air as well as electric energy also in the time of windlessness that is why we have to introduce the energetic and cubical piston compressor concept.

Table 1. **Setting of compressor power**
Tablica 1. **Podaci za određivanje potrebne snage kompresora**

Input parameters:		Output parameters:	
storage tank	$V = 2{,}7$ m^3		
pressure	$p = 800000$ Pa	mass flow	$m_k = 0{,}0015554$ kg/s
barometric pressure	$p_0 = 100000$ Pa	suction output	$v_s = 0{,}0013125$ m^3/s
temperature	$t_0 = 20$ °C	suction output	$v = 4{,}725$ m^3/h
time of tanking	$\tau = 14400$ s		
Reynolds number	$r = 288$ J·kg^{-1}·K^{-1}		

DETERMINATION OF THE ENERGETIC AND CUBICAL COMPRESSOR CONCEPT

Pressure tank should be filled with air from the compressor powered by mechanical energy from the wind equipment. We are considering a piston compressor for this purpose. Volume change of compressed air is caused by a direct reverse piston movement in the working area of the compressor. The working area of compressor is being formed of a working cylinder, which is closed by the cylinder cover from one side and from the other side the area is sealed by the piston. In the cover intake and forcing distribution valves are stored. On the cover of the cylinder also suction and delivery valves are located. The air compressor includes crank mechanism, connecting rod, piston gudgeon pin and caulking rings. The compressor piston is labelled as single-acting ($i = 1$), because during the air compression in the working area of the compressor only one frontal piston area is used.

Compressor efficiency [1, 2] is the amount of gas flowing during a time unit through the discharge branch of the compressor. Volume efficiency $\dot{v}$ / (m^3/h) is being re-counted to relative status, i.e. to pressure and temperature in suction branch. In technical conditions the efficiency is related to technically normal status (pressure p = 100 kPa and temperature t = 20 °C). Mass efficiency of the compressor $\dot{m}_k$ / (kg/h) is then re-counted volume efficiency of relative status.

Polytrophic exponent for older air compressors is n = 1,2, for newer air compressors it is n = 1,25 - 1,3 and for large compressors it is being considered n = 1,4.

Volume concept of the compressor is being solved by the construction concept of the main proportions of the compressor for requested efficiency. The result of the concept is a determination of the main proportions of the compressor piston, which are completed by revolutions of driven compressor shaft.

The energetic compressor concept is understood as the determination of the necessary compressor work, input and drive of the given compressor. In 10000 l pressure tank approximately 2,7 m^3 of air will be used for the work of pneumatic engine which we gained during pressure modification from 8000000 Pa to 630000 Pa.

The necessary suction output (Table 1.) and volume and energetic concept will be performed for an air storage tank with volume 10000 l (Table 2.).

Table 2. **Volume and energetic concept**
Tablica 2. **Volumen i energetski koncept**

Input parameters:		Output parameters:	
		piston speed	$c_s = 3{,}0$ m/s
		number of working surfaces	$i = 1$
suction output	$v = 4{,}725$ m^3/h	diameter of piston circles	$D = 0{,}0362$ m
pressure	$p = 800000$ Pa	chosen diameter	$D = 0{,}038$ m
barometric pressure	$p_0 = 100000$ Pa	stroke	$L = 0{,}0266$ m
temperature	$t_0 = 20$ °C	RPS	$n = 56{,}39$ s^{-1}
number of cylinders	$k = 1$	adiabatic power input	$P_{ad} = 372{,}76$ W
transport eficiency	$\eta_d = 0{,}85$	power input of compressor	$P_{ef} = 466$ W
		power of electromotor	$N_{el} = 564$ W

ENERGY ACCUMULATION

The problem of energy accumulation produced by the usage of wind, the production of economic and effective equipment is one of the basic tasks which need to be solved in the range of the question of using wind power. Selection of the type and capacity of the accumulation equipment coheres with the dependability of stored energy supply. In accordance to the versatility of wind conditions, as to difficult forecast of wind conditions, it is proper to provide the wind station with accumulation equipment, eventually to use a non-wind energy station.

The accumulation equipment observes following tasks:
- stabilization of variable aggregate output in the conditions of fluently changing wind velocities,
- harmonization of the production timetable graphics and energy consumption with the aim of delivering the energy to the consumer also in period in which the wind aggregate does not work or when its output comes short for connected loading,
- increase in total production of the wind equipment,
- increase in the effectiveness of wind energy usage,
- the possibility of gaining the peak output in short period of time.

Air accumulators are storage tanks into which air is being condensed by compressor powered by wind engine and consequently it is being consumed for the work of air engine. In the dependence of ordering the wind engine can be overcast by the compressor completely or partially, when it delivers part of the energy through the generator and the rest to the air accumulator. In the fist case a *capacitance accumulator* is considered which secures whole work of the station, and in the second case a *buffering* accumulator is considered which secures only the lacking energy of the wind engine at decreasing the wind speed.

Wind equipment using the energy of wind flow is powering the compressor, which compresses the air into pneumatic accumulators. From these storage tanks is the compressed air being used for the work of pneumatic engine of the working machine.

PNEUMATIC ENGINE AIR CONSUMPTION

Pneumatic engines are mechanical equipment intended for transformation of pneumatic energy of compressed air to mechanical energy [1, 2]. A big disadvantage is low effectiveness of pneumatic traction of approximately 15 %, as well as the necessity of air modification (contaminant and moisture removal). To the benefits belongs also the possibility of usage in industry in dusty and explosive environment, the ability of constant transferring to the maximum supercharge up to the total engine interception without drive protection and the start of the engine in full charge.

Air compressed by compressor is being forced down to storage tank, from where it is being used for work of the pneumatic engine which powers the generator. Asynchronous generator can be used as the generator. Asynchronous generator is the most frequent current resource at actual small wind power-stations. One of its advantages is dependability, simplicity and minimum maintenance requirements. As asynchronous generator it is possible to use almost every asynchronous electro engine with close-cut anchor without modifications.

1. Electromotor in the function of asynchronous generator can supply current only to public three phase electro-distribution network.
2. Electromotor in the function of asynchronous generator in common circumstances cannot be used in places where is this network missing. So it cannot work as an emergency resource during blackout or as the unique resource in non-electric locality.
3. It is not necessary to faze the generator to the network complicatedly.
4. The generator does not require any regulation of voltage and frequency.
5. The engine powering this generator does not need a revolution controller. The generator itself will slack up the water-wheel or the turbine to corresponding revolutions. Suitable gearing relation will secure the optimum mode of turbine work in that moment.

In calculations we get high air consumption $\dot{v}$ = 9,34 m^3/h (Table 3.) from which results the fact that a storage tank with volume 10 000 l and pressure 0,8 MPa should be able to power such pneumatic engine for 17 minutes.

Table 3. **Setting of air consumption of 4 vans pneumatic motor**
Tablica 3. **Podaci za određivanje potrošnje zraka pneumatskog motora s 4 lopatice**

Input parameters:		Output parameters:	
		indicated pressure	$P_{i,iz}$ = 498294 Pa
pressure	p_1 = 630000 Pa	power	W = 23,977 J
barometric pressure	p_2 = 100000 Pa	radius of stator	R = 0,03733 m
relative tanking	v_1/v_2 = 0,7	radius of rotor	r = 0,03061 m
RPS	n = 17,0 s^{-1}	length of rotor	L = 0,07466 m
mechanical efficiency	h_m = 0,8	excentricity	e = 0,00672 m
coefficient of vans thickness	k = 0,92	angle of next vans	α = 7,16
input power	N_{ef} = 1200 W	angle of next vans	β = 45
number of vans	z = 4	air consumption	v = 0,0026 m^3/s
		air consumption	v = 9,35 m^3/h

It is necessary to decrease the air consumption, and for this reason we are considering an equipment of the pneumatic winged engine with number of vanes 24.

Air consumption decreased to $\dot{v}$ = 5,48 m^3/h (Table 4.) This means that a storage tank with volume 10 000 l filled to pressure of 0,8 MPa, could power the pneumatic engine defined by us for 30 minutes.

WIND EQUIPMENT

The study comes from the philosophy of transformation of the wind kinetic energy, which passes through flow

Table 4. **Setting of air consumption of 24 vans pneumatic motor**
Tablica 4. **Podaci za određivanje potrošnje zraka pneumatskog motora s 24 lopatice**

Input parameters:		Output parameters:	
pressure	p_1 = 630000 Pa	indicated pressure	$P_{i,iz}$ = 498293,65 Pa
barometric pressure	p_2 = 100000 Pa	power	W = 3,9961637 J
relative tanking	v_1/v_2 = 0,7	radius of stator	R = 0,0373298 m
RPS	n = 17,0 s^{-1}	radius of rotor	r = 0,0306104 m
mechanical efficiency	h_m = 0,8	length of rotor	L = 0,0746596 m
coefficient of vans thickness	k = 0,92	excentricity	e = 0,0067194 m
input power	N_{ef} = 1200 W	air consumption	v = 0,0015224 m^3/s
number of vans	z = 24	air consumption	v = 5,48 m^3/h

area of wind engine into mechanical work necessary for compressor power. Wind engine transforms part of the energy into mechanical work, part of the energy stays unused and part of the energy of steady flow transforms into air whirling behind the rotor. This all comes from the theoretically possible wind usage.

According to the fact that we need a large torsion moment, we have to consider a multivane or Savonious rotor. In the blade rotor the air current flowing through the propeller area has the same effect for all fans during the propeller rotation. For the propeller drive are used aerodynamic forces of buoyancy and resistance of the aerodynamic profile. Output coefficient in correctly proposed propeller comes near to the theoretical value of Betz coefficient. It has relatively high revolutions suitable for generator drive. With the increasing number of propeller blades is the effectiveness decreasing, revolution by which is gained the maximum propeller effectiveness decline, but the torsion moment increases.

It is obvious in a multivane wheel which is during low revolutions more suitable for drive of piston pumps, as well as piston compressors, but not for the drive of generators for electric energy production. Multivan propeller is suitable for all places where it is necessary to lower the number of propeller revolutions. Slight lowering of the effectiveness will be replaced by increasing the rotor diameter.

In the case of Savonious rotor is the kinetic energy of air current transformed to pressure, which pushes the curved vane of the rotor in front of itself. Recessive vane is being driven by wind; progressive vane is being inhibited by the wind, so that a half of the rotor is participated in production of the torsion moment. Rotors of this type are suitable for pumps and similar equipments, which require large torsion moment but low revolutions. Since only a half of the rotor participates during the rotation in the production of torsion moment, the effectiveness is lower than the effectiveness of previous types.

According to technically usable wind velocity which is v = 3 m/s i.e. minimum wind velocity at which the wind equipment begins to work and the average wind velocity in Košice v = 3,6 m/s considered compressors connected to wind equipments are dimensioned to wind velocity v = 4 m/s using Savonious rotor (rotor area S = 57 m^2) or six-vane wind rotor (rotor area S = 26 m^2). The value of v = 4 m/s gains the wind in Košice and its outskirts mainly in afternoon hours.

CONCLUSION

Submitted work solves in an original way the usage of wind energy in outskirts of Košice, which is typical locality with average wind velocity 3,6 m/s with dominant northern current. According to the fact, that literature (and practice) considers cost-effective use of wind energy from the level of 5 m/s, we were searching for a solution, for which are the mentioned velocities sufficient. There has been introduced a solution, which should work as a top power-station, although in this case with a very low output. Here it is necessary to realize, that a new system solution is concerned and sequential modifications and improvements can emphasize the effect.

In the proposed solution are still not achieved results by which it would be possible to cover whole time of energetic peak, but there is a possibility of getting near to this point using pressure tank with higher pressure. In the proposed concept were used data about pressure tanks which are commonly available in Slovakia.

In comparison with such renewable resource of electric energy as are photovoltaic systems, whose output should gain level of 1,3 - 3 GW up to the year 2010, which is a total annual increase on the level of 580 MW [4], can the proposed wind energy usage system represent economic and technical solutions, as e.g. using the pressure tanks, a negotiable implementation way of RER (Renewable Energy Resources) into the energetic structures of the Slovak Republic.

REFERENCES

[1] M. Horák, P. Vančura,Technika stlačeného vzduchu. Návody na cvičenia. STU - Bratislava 1994.
[2] M. Horák, Technika stlačeného vzduchu. STU - Bratislava 1994.
[3] J. I. Šefter: Využití energie vetru. SNTL, Praha, 1991.
[4] D. Kováč, I. Kováčová: Behavior of the Voltage Measurement Transformer during Non Harmonic Signal Measuring, Power Electronics and Motion Control (1998), 152 - 155.
[5] L. Strakoš, Technická analýza vhodnosti využití různých typů rotorů pro pohon generátorů větrných elektráren. Větrná energie 1/07.
[6] V. Šimko, D. Kováč, I. Kováčová: Theoretical Electrotechnics I., Elfa s.r.o. Košice (2002), 173.
[7] P. Rybár, T. Sasvári, Zem a zemské zdroje. Elfa, Košice 1997.