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THE INFLUENCE OF THE NUMBER OF BLADES AND THE NUMBER OF LEVELS ON BEHAVIOR OF THE "S" -ROTOR EXPERIMENTAL MODELS

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ABSTRACT

The paper is based on wind tunnel (WT) experiments on experimental models (EMs), vertical axis wind turbines (VAWT), Savonius (SWT, "S" Turbine). The experimental models had the maximum dimensions: height of 0.395 m, and diameter of 0,150 m.

A study was conducted concerning the behavior of the EM experimental models for the level (1L) and three levels with a pair of blades (1PB) and a level with two pairs of blades (1L - 2PB). Wind speeds ranging from 0 to 2 m/s were used. Test section of the wind tunnel was 0,5 m x 0,5 m (0,25 m^2) and a shutter coefficient of 0,23. Experiments performed confirm the SWT's good behavior at low wind speeds and the possibility of being used to generate low-power electric power with DC generators.

KEYWORDS: vertical axis wind turbines, Savonius wind turbine

1. Introduction

Vertical axis wind turbines (VAWT) remain attractive for residential scale applications because the low conversion efficiency (Betz Limit, max. 14.81%) is offset by the performance of other system elements: battery buffers, LED (light emitting diode) lighting systems, high input voltage converters and all this at increasingly low prices [1, 2]. The only condition is the existence of a wind of 3 to 7 m/s for as long as possible in the year to make an investment efficient [3, 4]. Furthermore, the evolution of microprocessor-based electronic systems allows the management of dual power systems with wind turbine (Renewable Energy Sources - RES) and grid power, or triple power supply: solar, wind (RES) and grid [2]. All this leads to the use of Savonius wind turbines (SWT) as a primary source of mechanical work taken from wind energy and conversion to electricity with permanent magnet generators. The only condition is that SWT approaches with efficiency as much as 14.81%.

The power of wind (P) depends on wind speed (v), air density (ρ) and swept area (A):

$$P = 0{,}5\rho A v^3 \qquad (1)$$

The power extracted from a wind power by a VAWT Savonius type is depending by Drag force as follows:

$$D = C_D \frac{1}{2}\rho(v-u)^2 A \qquad (2)$$

where: u – is blade speed.

The power of wind becomes:

$$P = D_u = C_D \frac{1}{2}\rho v^3 (1-\frac{u}{v})^2 \frac{u}{v} A \qquad (3)$$

When $\lambda = \frac{u}{v}$, the extracted power becomes [5]:

$$P = C_D \frac{1}{2}\rho v^3 (1-\lambda)^2 \lambda A \qquad (4)$$

2. Materials and experimental conditions

For experimental testing, the following SWT models were used:

- EM1 (SWT-1L-1PB) made according to the classic SWT structure, two semi-cylindrical blades (one pair of blades, 1PB) on a level (1L) as is shown in Figure 1.
- EM2 (SWT-1L-2PB) made with four semi-cylindrical blades (two pairs of blades, 2PB) on a level (1L) as is shown in Figure 2.

- EM3 (SWT-3L-1PB) made with three levels (3L) of one pair of semi-cylindrical blades (1PB) as is shown in Figure 3.

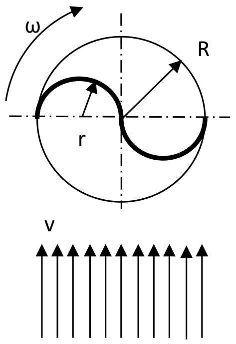

Fig. 2. *Transversal section through EM1 (SWT-1L-1PB)*

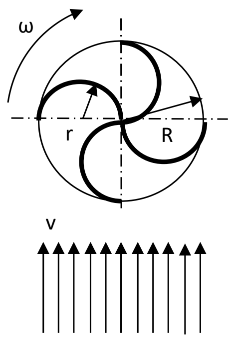

Fig. 2. *Transversal section through EM2 (SWT-1L-2PB)*

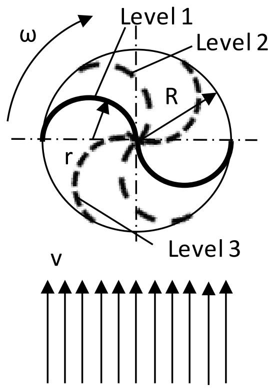

Fig. 3. *Image with EM3 (SWT-3L-1PB)*

The common features of the experimental models (EM1, EM2 and EM3) are shown in the Table 1 and the experimental conditions are presented in Table 2.

The Table 3 shows the wind characteristics of the wind tunnel (WT).

The wind tunnel used offers conditions for experimenting with experimental models at low wind speeds (< 4.5 m/s). The test section is 0.5 m x 0.5 m (0.25 m^2). The area occupied by the model is 23.5% of the measurement section. Real speed increases with the same percentage according to the Bernoulli equation. Wind speed was measured with LCA6000 anemometer. The speed of the experimental model is measured with the reed sensor and the Ventura IV system.

Table 1. *Experimental model common characteristics*

no.	symbol	characteristics	m.u.	relation	value	observation
1	H	high	m		0,39	input
2	R	rotor radius	m		0,075	input
3	D	rotor diameter	m	D=2R	0,15	
4	r	blade radius	m	r=R/2	0,0375	
5	AR	aspect ratio	-	Ar=H/D	2,6	
6	N	blade number	-	0	4	variable 1...4
7	k	level number	-	0	1	variable 1...3
8	0	blade airfoil	-	0	-	semi-cylindrical surface
9	h	blade high	m	h=r	0,022	
10	gm	depth blade material	m		0,002	input
11	PEc	blade material ME	-		-	PE
12	lb	blade long	m	lb=πr	0,118	
10	Ad	total blade surface	m2	Ad=lp.H	0,046	
11	As	rotor swept area:	m2			
12	Asmin	min	m2	Amin=hH	0,017	
13	Asmax	max	m2	Amax=R. H	0,059	
14	τ	solidity:	-			
15	τmin	solidity, min	-	τmin=Amin/Amax	0,293	
16	τmax	solidity, max	-	τmin=Amax/Amax	1	
17	a	gap	m		-	no gap
18	o	overlay	m		-	no overlay
19	m	total model mass	kg			measured

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Table 2. *Experimental conditions*

no.	symbol	characteristics	m.u.	relation	value	observation
1	t	air temperature	◦C		25	measured
2	T	absolute air temperature	K	Ta=ta+273,16	298,16	
3	0	air humidity	%		0,3	(Nelson, 2009), weather
4	ρ	standard air density	kg/m3	-	1,225	la 15°C, nivelul marii
5	ρa	real air density	kg/m3	ρa=(353,049/T)e-0,034 z/T	1,17872	(Nelson, 2009), with corrections
6	Pr	air pressure	mmHg		780	weather
7	ϑ	kinematic air viscosity	m2/s		1,6E-05	(Matthews C, 2002)
8	ηa	dynamic air viscosity	Ns/m2		2E-05	(Matthews C, 2002)
9	VP	presiunea de vapori	mmHg		0	0
10	z	altitude	m		40	Galati city
11	τ	time	s		60	measured
12	CD	aerodynamic drag coefficient SWT	-		1	(Nelson, 2009)
13	ω	angular velocity	rad/s	ω=2πn; ω=2πf		variable
14	rev	revolutions	rpm			measured
15	I	moment of inertia	kgm2	I=mr2	0,00041	1rev=360°=2π;
16	m	mass of experimental model	kg	0	0,072	se măsoară pe balanță
17	Erot	kinetic energy (rotational)	J	Erot=1/2 Iω2		variable
18	v	wind speed	m/s			anemometer
19	u	tip speed	m/s	u=ωr		variable
20	λ	tip speed ratio,TSR	-	λ=u/v; λ=ωD/2u		variable
21	n	rotor speed (revolutions)	rpm			measured
22	σ	rotor solidity	-	σ=Nc/R	1	

Table 3. *Wind characteristics*

symbol	v	Ev	Pv	pv	0
u.m.	m/s	J	W	W/m2	W
1	4,25	158,80	2,65	45,24	0,39
2	3,81	114,41	1,91	32,60	0,28
3	2,62	37,20	0,62	10,60	0,09
4	2,48	31,55	0,53	8,99	0,08
5	2,21	22,33	0,37	6,36	0,06
6	2,01	16,80	0,28	4,79	0,04
7	1,80	12,06	0,20	3,44	0,03
8	1,59	8,32	0,14	2,37	0,02
9	0	0	0	0	0

The wind tunnel used offers conditions for experimenting with experimental models at low wind speeds (< 4.5 m/s). The test section is 0.5 m x 0.5 m (0.25 m^2). The area occupied by the model is 23.5% of the measurement section. Real speed increases with the same percentage according to the Bernoulli equation. Wind speed was measured with LCA6000 anemometer. The speed of the experimental model is measured with the reed sensor and the Ventura IV system.

Experiments were performed without mechanical or electrical load. All outputs are directly or indirectly dependent on wind speed in the tunnel [6-8]. For wind tunnel experiments on the EM1, EM2 and EM3 the maximum wind speed was 4.2 m/s.

3. Results and discussion

The resulted data are shown in terms of rotation speed (Figure 4), the power at the EM axis (Figure 5), Reynolds Number (Figure 6), power to the turbine shaft (Figure 7), specific speed (Figure 8) and axle frequency (Figure 9) for different wind speed (0 – 4.2 m/s).

The experimental results corresponding to SWT-1L-1PB are presented in Table 4, in Table 5 for SWT-1L-2PB and in Table 6 for SWT-3L-1PB. The rotational speed of the experimental models is shown in Figure 4.

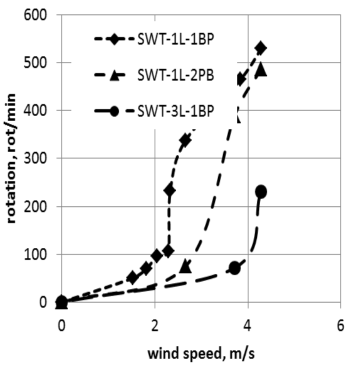

Fig. 4. *Rotation speed depending on wind speed for EM1, EM2 and EM3*

Table 4. *Results for experiments with SWT-IL-1PB*

symbol	n	0	f	ω	u	λ	Re	P/A	Pa	η
u.m.	rpm	rot/s	Hz	rad/s	m/s	-	-	W/m2	W	-
1	530	8,83	8,83	55,47	4,16	0,97	84908	0,04	0,00	0,00
2	465	7,75	7,75	48,67	3,65	0,95	74495	0,07	0,00	0,00
3	338	5,63	5,63	35,38	2,65	1,00	54149	0,00	0,00	0,00
4	232	3,87	3,87	24,28	1,82	0,78	37167	0,30	0,02	0,04
5	107	1,78	1,78	11,20	0,84	0,37	17142	2,41	0,14	0,34
6	96	1,60	1,60	10,05	0,75	0,37	15380	1,72	0,10	0,34
7	70	1,17	1,17	7,33	0,55	0,30	11214	1,47	0,09	0,41
8	50	0,83	0,83	5,23	0,39	0,26	8010	0,97	0,06	0,46
9	0	0,00	0,00	0,00	0,00	0,00	0	0	0	0

Table 5. *Results for experiments with SWT-IL-2PB*

symbol	n	0	f	ω	vt	λ	Re	P/A	Pa	η
u.m.	rot/min	rot/s	Hz	rad/s	m/s	-	-	W/m2	W	-
1	486	8,10	8,10	50,87	3,82	0,89	77859,18	0,41	0,02	0,01
2	388	6,47	6,47	40,61	3,05	0,82	62159,18	0,67	0,04	0,02
3	75	1,25	1,25	7,85	0,59	0,22	12015,31	1,26	0,07	0,11
4	0	0	0	0	0	0	0	0	0	0

Table 6. *Results for experiments with SWT-3L-1PB*

symbol	n	0	f	ω	vt	λ	Re	P/A	Pa	η
u.m.	rot/min	rot/s	Hz	rad/s	m/s	-	-	W/m2	W	-
1	231	3,85	3,85	24,18	1,81	0,42	37007	5,52	0,32	0,12
2	71	1,18	1,18	7,43	0,56	0,15	11374	2,77	0,16	0,09
3	0	0	0	0	0	0	0	0	0	0

From Figure 4 it can be seen that the Savonius wind turbine with 1L-1PB (EM1) has the highest rotational speed compared to the other two models (EM2 and EM3).

Figure 5 presents the power at the EM axis depending on the wind speed.

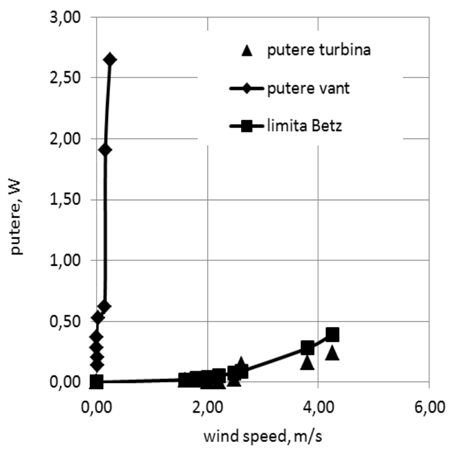

Fig. 5. *The power at the EM axis depending on the wind speed*

In Figure 6 are presented the calculated Reynolds number as a function of wind speed and Figure 7 indicates the variations of turbine wind power with the different wind speeds.

In Figure 7 it can be clearly seen that the best values in terms of turbine wind power correspond to experimental model EM3, which has the most even torque and the best start.

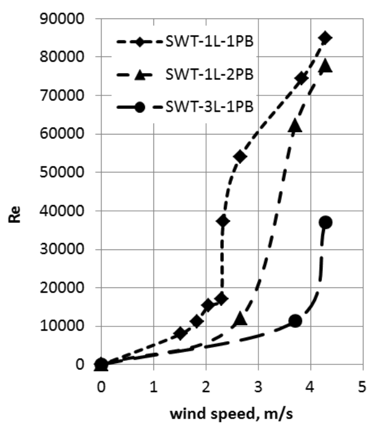

Fig. 6. *Variation of Re with wind speed*

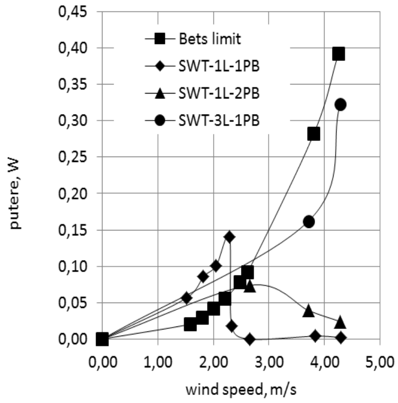

Fig. 7. *Turbine wind power for the experimental models depending on the wind speed*

In Figure 8 is presented the variation of specific speed as a function of wind speed.

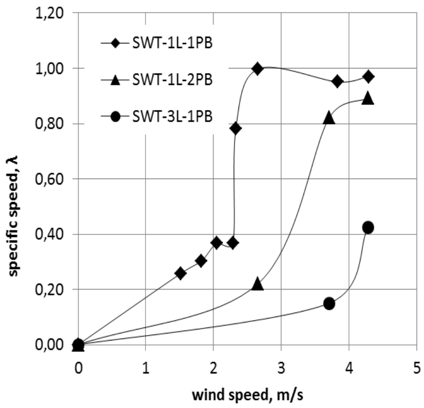

Fig. 8. *Specific speed (speed ratio) depending on wind speed*

Figure 9 shows the axle frequency variations depending on wind speed.

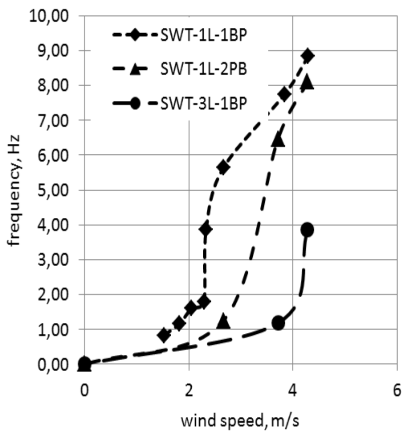

Fig. 9. *Axle frequency with wind speed*

Figure 9 shows that frequency of rotations of SWT axle has to small value for directly coupled to grid being necessary a mechanical multiplier with i=10 for EM1 and EM2 and a centrifugal regulator.

Figure 10 presents the variation of Re number depending on specific speed for all three experimental models tested.

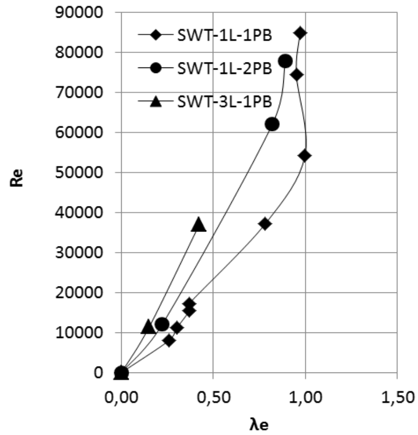

Fig. 10. *Re number variation with specific speed for EM's*

From Figure 10 it can be seen that the only EM that approaches $\lambda = 1$ is EM1 (classical SWT with 1L and 1PB). For the same λ, Re number is higher for SWT with 2PB and for $\lambda < 0,5$ SWT with 3L and 1PB and each level offset at 120 °.

4. Conclusions

The best behavior in experiments was EM1 (classic Savonius wind turbine) with S-shaped blades which is consistent with: best sensitivity to the wind speed high rotation speed, high specific speed (close to 1) and a higher Re number.

The only problem is the low power which can develop at the shaft, and that the experiments recommend it for small powers.

For a higher power and with a possible greater uniformity at coupling, three-levels EM3 may be recommended.

For the use of turbines with a DC electric generator with permanent magnets with a one pair of magnetic pole, a speed around of 1200 rpm is required and a multiplier of i = 5 is required.

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