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[1]V. M. Sineglazov,
[2]A. A. Ziganshin

OPTIMIZATION OF SAVONIUS ROTOR PARAMETERS

Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]svm@nau.edu.ua, [2]anwarzihan@gmail.com

Abstract*—*An extensive survey of experimental and numerical investigations devoted to predicting optimal parameters of the isolated Savonius rotor and in a couple with .the given Darieus one was done. Basing on review recommendations were given to determining of optimal parameters for obtaining the maximum starting torque of Savonius rotor.

Index Terms—Aerodynamics; overlap; Savonius rotor; torque; vertical axis wind turbine.

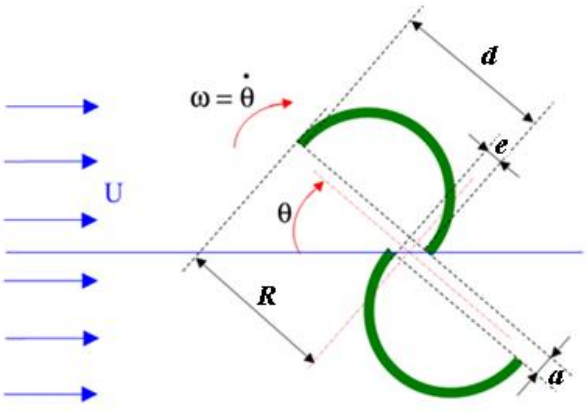
I. INTRODUCTION

Usage of a Darieus rotor for vertical axis wind turbines is preferable at mean and high wind speeds. A Savonius rotor shows high performance at low wind speed. Usualy in Ukraine wind blows with low and mean speeds. It was a good idea to apply a combined Savonius-Darieus rotor due to the high starting torque of the Savonius rotor. In this paper the choice of optimal parameters was done for the Savonius rotor in combination with given the Darieus one.

II. REVIEW OF PAPERS ON PARAMETRICAL INVESTIGATOINS FOR IMPROVING THE PERFORMANCE OF SAVONIUS ROTOR

Jean Luc Menet and Nachida Bourabaa [1] based on parametric studies showed that the number of steps should be at least two, and you could practically limited to two. It was also pointed out that the number of blades must be greater than two because of that it decreases unevenness the torque of a blade with the angular azimuth θ (Figure). Overlap ratio e/d ranged from 0.15 to 0.3. They obtained the optimum at $e/d = 0.242$ for the torque moment. With increasing Reynolds number from 100 000 to 440 000 the torque coefficient had trend to grow from 0.328 to 0.334.

Md. Nahidul Islam Khan et al. [2] conducted a study in the water on the effect of the number of stages on the performance of the two bladed Savonius rotor. Since the blades had phase difference the unevenness of torque with azimuth angle decreased with growth of the number of stages. Single stage and three stage rotors showed almost the same power. Power maximums for the single- and the two stage rotors were obtained at the tip speed ratio 0.8, and for the three stage one - at 0.7. In this sense, a single stage rotor was more preferable than a three stage one. The most effective option was the two stage rotor due to the most power output.



Scheme of a Savonius rotor: *U* is the wind speed; θ is the angukar azimuth for a blade; ω is the angular speed; *R* is the rotor radius; *d* is the blade chord; *a* is the gap; *e* is the overlap

S. M. Rassoulinejad-Mousavi et al. [3] regarded an internal and an upper arrangement of the Savonius rotor for the combined Darieus-Savonius H-rotor. More power and moment were obtained for the upper Savonius rotor position.

Mohamed Hadi Ali [4] showed experimentally that averaged torque and power coefficients for the two bladed rotor were more than those for the three bladed one. So with the increase in the number of blades the negative moment of the returning blades grows.

Mahmoud N.H. et al. [5] studied experimentally ways of improving the Savonius rotor efficiency. It was noted that the two stage rotor was preferable than the single stage one. Also the two bladed rotor was advantageous than the three- and four bladed units. An option without a gap was the most effective for torque and power. Aspect ratio increasing led to growth of torque and power coefficients.

Jerzy Swirydczuk et al. [6] investigated the unsteady flow through the gap between the two blades of the Savonius rotor. It was assumed that the power of the vortex generated in the gap can affect the efficiency of the rotor. The ends of blades in the gap af-

fect the formation of the vortex. Also the effect of the overlap ratio (e/d from 0.1 to 0.2) on the efficiency of the rotor was studied. An optimum was obtained at e/d = 0.17. Krzysztof Rogowski and Ryszard Maroński [7] also investigated the effect of the gap between the two blades of the Savonius rotor on the torque and power coefficients. Two cases of the gap ratio a/d (0.1 and 0.2) were regarded. Improvement took place in the case of smaller gap.

A. A. Kadam, et al. [8] showed experimentally that the rotor with two blades was more stable in work and the increase in rotor aspect ratio gave the gain in the power coefficient. They examined the overlap ratio effect e/d in the range from 0.162 to 0.35. The best result was found to be e/d = 0.162. Also Patel C. R. et al. [9] considered three options of the overlap ratio (0, 0.1 and 0.2) for the two bladed Savonius rotor. Maximum power and torque coefficients are obtained at the overlap ratio e/d = 0.2 for all values of tip speed ratio. In addition Sukanta Roy [10] presented the influence of the overlap ratio e/d in the range from 0 to 0.3. Analysis at e/d = 0.2 showed that the negative moment disappeared thereby reducing the torque unevenness with the angular azimuth of the blades.

K. K. Sharma et al. [11] obtained an optimal overlap ratio e/d = 0.0937 for the two stage two bladed Savonius rotor giving the maximums moment (0.744) and power coefficients (0.517) at the tip speed ratio 0.697. Further growth of the overlap ratio up to 0.1987 was decreasing the power and torque coefficients only.

K. K. Sharma et al. [12] studied the work of the three bladed combined Darieus-Savonius rotors. The Savonius rotors with different overlap ratios e/d from 0.108 to 0.258 were installed on the top of the Darieus rotor. It was found that at tip speed ratio 0.604 the power coefficient reached a maximum (0.53) at a overlap ratio e/d = 0.168. Also Animesh Ghosh et al. [13] studied the effectiveness of the Savonius rotor, Darieus H-rotor and combined Darieus-Savonius one. The Savonius rotor was regarded at different overlap ratios e/d from 0.162 to 0.35. The results showed that at tip speed ratio 0.625 the power coefficient reaches the maximum (0.38) at a overlap ratio e/d = 0.2.

R. Gupta et al. [14] had the effect of overlap ratio (e/d from 0 to 0.2) of the two bladed Savoniu rotor on the performance in combination with a three-bladed Darieus rotor. It was noted that the greatest increase in the torque and power coefficients was at e/d = 0.2. O.B. Yaakob et al. [15] experimentally and numerically studied the effect of the overlap ratio between 0 and 0.3 for the two bladed Savonius rotor. The maximum starting torque was obtained at the value of e/d = 0.21. It was concluded that the optimum overlap ratio ranges from 0.2 to 0.25. Also Sargolzaei J. [16] indicated the optimum power coefficient for a single stage two bladed Savonius rotor at the overlap ratio e/d = 0.2 from the considered range of between 0 and 0.45. Gupta et al. [17] studied the effect of overlap ratio e/d in the range from 0.1087 to 0.2587 for the combined Darieus-Savonius rotor (both had three blades). Optimum overlap ratio 0.1537 for the maximum power coefficient was obtained.

Modi V. J., Roth N. J. and Fernando M. S. U. K. [18] conducted a parametric study of the two stage two bladed Savonius rotor with an airfoil proposed by G. Bach [19]. It was noted that the improvement of the rotor was observed for the overlap ratio $e/d >$ 0.22. It was suggested that the reduction of the gap could lead to improving the rotor performance. The two stage rotor was preferable than a single stage one.

M. A. Kamoji et al. [20] conducted an experimental study to determine the influence of geometrical parameters on the starting moment, torque and power coefficients of a single stage two bladed Savonius rotor with the Bach airfoil [19] with and without the shaft [18]. It was noted that the rotor without the shaft, the zero-gap, aspect ratio 0.7 and the ratio of outer to inner diameters 1.1 gave the greatest power coefficient 0.21 at the tip speed ratio 0.69 and the Reynolds number of 150,000.

Benedicto Mark Rudolph A. et al. [21] studied in water the effects of the number of blades and the overlap on the performance of the Savonius rotor. Simulation has been conducted by varying the number of blades from two to three of single stage rotor systems. The power coefficient of the three bladed rotor has the less value than the two bladed one has. Also it was supposed that there must be an appropriate overlap ratio value which could lead to the better Savonius turbine.

Ibrahim Mabrouki et al. [22] implemented the experiments in water for a two bladed single stage Savonius rotor and showed that increasing in the overlap ratio from 0 to 0.3 improved power and dynamic torque coefficients.

K. K. Sharma and R. Gupta [23] tested in a wind tunnel three models of rotors like two bladed Savonius rotors, three bladed Savonius rotors and two bladed two stage Savonius rotors having various overlaps (from 0.0938 to 0.2587) in each type of rotor. For the two bladed Savonius rotor maximum rotational speed obtained at the overlap ratio 0.0938. The same speed for the three bladed rotor was obtained at the overlap ratio 0.1087. For the two bladed two stage Savonius rotor (having the 90 degrees of

phase difference) maximum rotational speed was obtained at the overlap ratio 0.1538.

Ali Mohamed Elmabrok [24] compared the three variants of the Savonius rotor in a couple with the Darieus rotor. It was considered options like semi-circular cylinders without overlapping $e = 0$; semi-circular cylinders with overlapping $e/d = 0.25$ and with the profile proposed by G. Bach [19] for the overlap ratio $e/d = 0.25$. It was shown that the best one was the third option because it could drive the rotor at lower wind speeds.

Khandakar Niaz Morshed [25] and with the others [26] studied the combined effect of overlapping blades (e/d varied from 0 to 0.26) and the Reynolds number on the efficiency of the three bladed Savonius rotor. It was observed that the best result was obtained at high Reynolds numbers without the overlapping and also at low Reynolds numbers with the moderate overlap ($e/d = 0.12$). Furthermore with increasing Reynolds number the torque coefficient slightly increases.

Ben F. Blackwell et al. [27] conducted extensive experimental studies Savonius rotors with various parameters. Thus the two bladed Savonius rotor had better characteristics than the three bladed one. The Reynolds number growth led to improve the performance. Efficiency increased slightly with the aspect ratio growth. The gap ratio a/d ranged from 0.1 to 0.15 could provide the optimum performance. The two stage two bladed unit having the phase difference of 90 degrees was recommended.

III. Task statement

It was evident that with the augmentation of the rotor diameter and its height an increase in torque and power took place. Taking into account the review the task statement was to find Savonius rotor (see Figure) parameters (number of semi-cylindrical blades, gap ratio, overlap ratio) for maximizing the starting torque to the next constraints:

– number of stages equals 2;

– rotor diameter ($D = 2R$) must be as large as possible;

– stage height must be as big as possible or at $H = 0.77D$ at least;

– number of blades is from 2 to 3;

– gap ratio a/d is from 0 to 0.2;

– overlap ratio e/d is from 0 to 0.35.

An assumption that the interaction between the stages of rotors being negligible was accepted.

Conclusions

The recommendations were given to determining of optimal parameters for obtaining the maximum starting torque of Savonius rotor. It is necessary conducting the further investigations

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Sineglazov Viktor. Doctor of Engineering. Professor.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kiev Polytechnic Institute. Kiev, Ukraine (1973).
Research interests: Air Navigation, Air Traffic Control, Identification of Complex Systems, Wind/solar power plant.
Publications: more than 450 papers.
E-mail: svm@nau.edu.ua

Ziganshin Anwar. Asistant.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kazan Aviation Institute. Kazan, Russia (1978).
Research interests: computer aided design systems, numerical methods in aerodynamics.
Publications: 1.
E-mail: anwarzihan@gmail.com

В. М. Синєглазов, А. А. Зіганшин. Оптимізація параметрів ротора Савоніуса для комбінації із заданим ротором Дар'є

Проведено широкий огляд досліджень, присвячених визначенню оптимальних параметрів ізольованого ротора Савоніуса та у парі з заданим ротором Дар'є. На основі огляду надано рекомендації з вибору оптимальних параметрів ротора Савоніуса для отримання максимального пускового моменту.

Ключові слова: аеродинаміка, вітроенергетична установка з вертикальною віссю обертання, перекриття, обертальний момент, ротор Савоніуса.

Синєглазов Віктор Михайлович. Доктор технічних наук. Професор.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут. Київ, Україна (1973).
Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем, вітроенергетичні установки.
Кількість публікацій: більше 450 наукових робіт.
E-mail: svm@nau.edu.ua

Зіганшин Анвар Абдуллович. Асистент.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Казанський авіаційний інститут. Казань, Росія (1978).
Напрям наукової діяльності: системи автоматизації проєктувальних робіт, числові методи в аеродинаміці.
Кількість публікацій: 1.
E-mail: anwarzihan@gmail.com

В. М. Синеглазов, А. А. Зиганшин. Оптимизация параметров ротора Савониуса для комбинации с заданным ротором Дарье

Проведен обширный обзор исследований, посвященных определению оптимальных параметров изолированного ротора Савониуса и в паре с заданным ротором Дарье. На основании обзора даны рекомендации по выбору оптимальных параметров ротора Савониуса для получения максимального пускового момента.

Ключевые слова: аэродинамика, ветроэнергетическая установка с вертикальной осью вращения, перекрытие, вращающий момент, ротор Савониуса.

Синеглазов Виктор Михайлович. Доктор технических наук. Профессор.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт. Киев, Украина (1973).
Направление научной деятельности: аэронавигация, управление воздушным движением, идентификация сложных систем, ветроэнергетические установки.
Количество публикаций: больше 450 научных робот.
E-mail: svm@nau.edu.ua

Зиганшин Анвар Абдуллович. Асистент.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Казанский авиационный институт. Казань, Россия (1978).
Направление научной деятельности: системы автоматизации проектирования, численные методы в аэродинамике.
Количество публикаций: 1.
E-mail: anwarzihan@gmail.com