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J. Swirydczuk, K. Kludzinska

Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdansk, Poland

IMPROVING SAVONIUS ROTOR PERFORMANCE BY SHAPING ITS BLADE EDGES

The article presents the results of the numerical analysis of the flow inside the Savonius rotor. Particular attention has been paid to the vicinity of the blade gap in order to recognise the mechanisms controlling the flow in this area. The conclusions resulting from the analysis made the basis for an attempt to improve Savonius turbine performance via shaping rotor blade edges. The paper presents selected characteristic flow patterns in the vicinity of the blade gap and the results of blade edge shaping having the form of torque fluctuations recorded during one half-period of rotor rotation.

Key words: *Savonius rotor, blade gap, vortices, performance improvement.*

Introduction

The sale of small wind turbines for individual users in Poland is addressed to two main areas. The first area includes individual farm owners whose power needs can be evaluated as being of an order of 5 kW to cover all-day consumption for hot water and electricity. The second area is summer houses which need electricity ranging between 0.5 and 1.0 kW. Unfortunately, it is the high price of wind turbines which makes the basic barrier discouraging individual users from buying. This high price is connected with the fact that most turbines offered on the market are advanced designs of horizontal-axis type (HAWT) with complicated mechanical part used for collecting energy from the wind. In this context, offering other innovative turbine types and modern technologies which provide opportunities for decreasing this price considerably is believed to be attractive and welcome by the market.

The object which seems to be able to meet the expectations for a small, cheap and efficient wind turbine for an individual user is a vertical axis wind turbine (VAWT) of Savonius type. The turbine was invented by Sigurd Savonius, a Finnish engineer, in 1924. It consists of two semicircular blades displaced eccentrically with respect to each other along the line crossing blade edges. The blades are fixed between two endplates, the role of which is to make the flow inside the rotor regular. The principle of operation of the Savonius turbine is the drag difference between two blades mowing with and against the wind, see Fig.1.

Generally, Savonius turbines are used when their efficiency is less important than the cost and/or the reliability of operation. They have been an object of research for decades. The past investigations, mostly of experimental nature and done using relevant measuring and visualisation techniques, aimed at assessing the influence of selected geometrical parameters, such as the central gap width, the *H/D* ratio, and/or the number of rotor blades and sections, on turbine performance [1] – [5]. Only recently, following rapid development of computer hardware and software, numerical analyses were done using the vortex method [6], [7] and the finite volume method [8] to study in detail the unsteady flow through a rotating Savonius rotor.

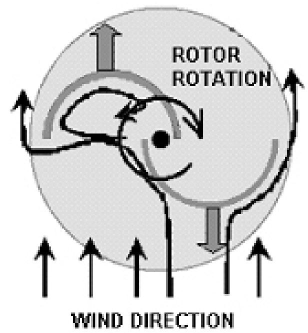
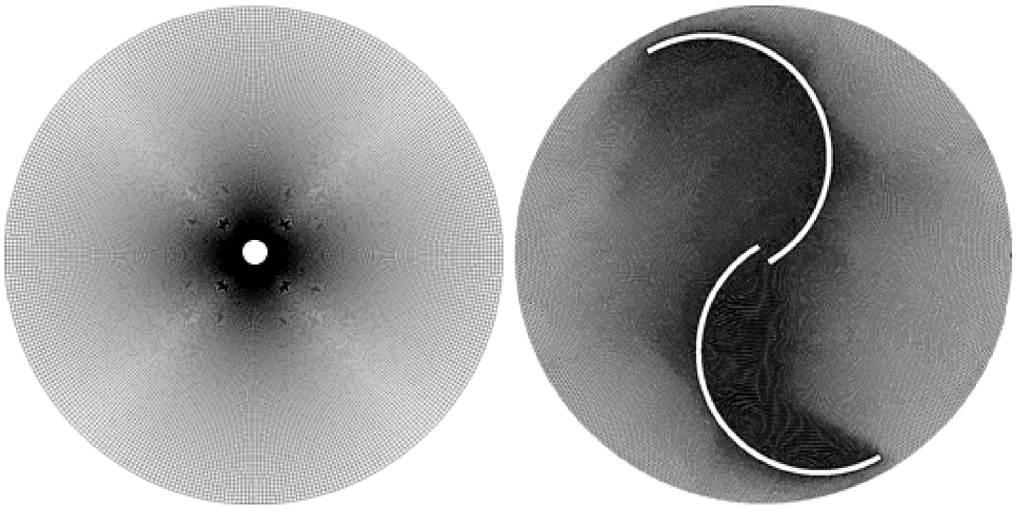


Fig. 1. Principle of Savonius rotor operation

The present article, making part of comprehensive studies of Savonius rotor operation, analyses the flow in the vicinity of the rotor blade edges, especially the blade gap, and suggests possible blade shape modifications to improve turbine performance. The analysis is done in two dimensions to have an opportunity to trace the unsteady flow phenomena with the maximum possible resolution.

1. Geometry and flow parameters

The examined Savonius rotor consisted of two half-cylinder blades having the outer diameter d=200 mm and thickness of 5 mm. The overall diameter of the rotor, D, was 380 mm and the eccentricity, e/d, was 0.1.



a b
Fig. 2. Two grid blocks:
a — outer block; b — inner block inside the rotor

The total number of elements of the calculation grid was about 1.2 million. The entire calculation domain was divided into two main blocks, one of which covered the area outside the rotor while the other — inside. The ratio between the diameter of the outer and inner block was 20. Between the two main blocks, a sliding mesh concept was used to allow their relative movement. The outer block was semi-structured, with increasing cell dimensions towards the outer boundary, Fig 2a. The block inside the rotor had an unstructured grid consisting of mostly tetrahedral elements, Fig. 2b. Near the walls, the wall function approach was used to provide acceptable boundary conditions for the mean flow. The maximal values of y^+ did not exceed 3 and the average value of y^+ was not larger than 1.

The 2D calculations were performed with the aid of the commercial code Fluent-ANSYS. The external boundary condition for the outer grid block was defined using the far field concept, in which the wind velocity was set to $U = 8$ [m/s], and the ambient temperature to 290 K. The Spalart-Allmaras single-equation turbulence model was used. This turbulence model was selected after overviewing other available publications on CFD calculations carried out in similar geometry and flow conditions to arrive at a reasonable compromise between the expected accuracy and time spent to achieve it, an important factor in any unsteady calculations.

The angular velocity of the rotating domain of the rotor was assumed as $\omega=2\pi$[Hz] which corresponded to one turn per second. The time step of the unsteady calculations corresponded to one degree of revolution and was approximately equal to $\Delta t = 0.0028$[s].

The unsteady flow was calculated until sufficient repeatability of the torque time-history over a half-revolution period was obtained. It turned out that a satisfactory number of rotor half-revolutions to obtain this stability did not exceed three.

2. Flow structure in the blade gap

One of initial steps of the here reported research of the Savonius turbine was analysing the unsteady flow inside the rotor during its rotation, with particular attention being paid to the vicinity of the blade gap, the most characteristic element of the Savonius rotor. Firstly, the mass flow rate Q of the air flowing through the gap was calculated as the function of the rotor rotation angle α.

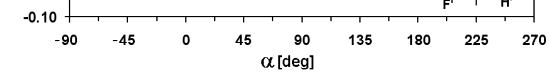
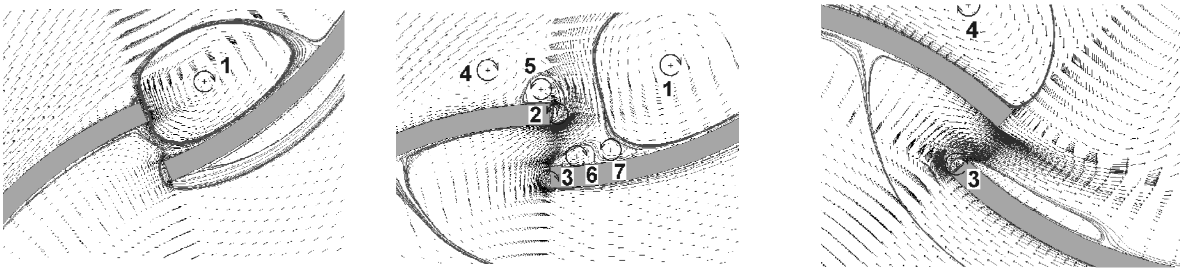


Fig. 3. Air mass flow rate through the blade gap

Changes of the mass flow rate recorded during one half of rotor rotation (180 degrees) are shown in Fig. 3 as the black continuous curve. The axial symmetry of the Savonius rotor has made it possible to extend this curve over the next 180 degrees, the dashed part, thus obtaining the blade gap mass flow rate fluctuations over the entire rotor rotation. The result of these calculations, complemented by the visual definition of the rotation angle, is shown in Fig. 3.



a b c

Fig. 4. Flow patterns in the vicinity of blade gap in selected angular rotor positions:
a – position D: no flow through the gap; b – position E: formation of vortices; c – position G: maximal gap flow

The labels **A** to **I** in the diagram in Fig. 3 mark the air mass flow rates for which data sets with full distributions of flow parameters were recorded. The first data set **(A)** was recorded when the rotor occupied the position perpendicular to the air flow direction, i.e. for the rotation angle equal to α = -90 deg. The next data sets corresponded to consecutive rotation angles differing by 22.5 deg, with the last data set **(I)** recorded for α = +90 deg. Here again, the symmetry of the Savonius rotor geometry has made it possible to extend the representativeness of these distributions over the entire rotor rotation, i.e. 360 degrees.

The curve shown in Fig.3 reveals two characteristic rotation angles labelled **D** (α = -22.5 deg) and **G** (α = 45 deg). When the instantaneous rotor position corresponds to angle **D**, there is no flow through the blade gap. The velocity field and streamline distribution recorded in this angular position of the rotor are shown in Fig. 4a. The only noticeable structure here, visualised by the arrangement of velocity vectors, is a clockwise rotating vortex 1 whose activity determined by the actual position and strength effectively blocks the gap.

With time, when the rotor keeps rotating, the gap vortex 1 moves off, thus opening the gap and allowing the air to flow through the gap. Simultaneously, a series of new vortices are formed near blade edges, Fig. 4b.

During further rotation of the Savonius rotor some of these vortices vanish while the others become more intensive. The vortex configuration observed in the second characteristic rotor position **G** revealing the maximal flow rate trough the gap is shown in Fig. 4c. The flow is regular, with the presence of only one small vortex **3** in the direct vicinity of the blade edge. With time, this vortex gains in strength and finally separates from the blade edge becoming again the main gap vortex **1**, which was already observed in Fig. 4 as the structure blocking the gap. Then the entire cycle repeats, with the reverse role played by each blade.

3. Blade edge shape modification

The above descri ption of the flow phenomena taking place in the vicinity of the blade suggests that the flow though the gap is strongly affected by vortex structures temporarily forming in this area. Therefore a reasonable way to control this flow and, consequently, overall performance characteristics of the Savonius turbine is to change the shape of blade edges.

The simplest way to shape the inner blade edges is bevelling. A series of examined bevel angles is shown in Fig. 5. In these examinations the shape of the outer blade edge remained square.

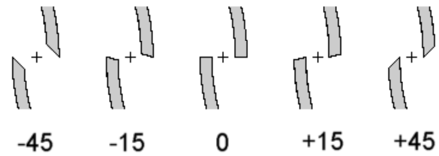


Fig. 5. Examined bevel angles of inner blade edge

Figure 6 presents torque coefficient distributions for various bevel angles of the inner blade edges. The torque coefficient C_T was calculated from the formula:

$$C_T = \frac{T}{\frac{1}{4}\rho U^2 D^2 H} \qquad (1)$$

where: T - torque;
ρ – air density;
U – free stream velocity of the wind;
D - Savonius rotor diameter;
H - Savonius rotor height.

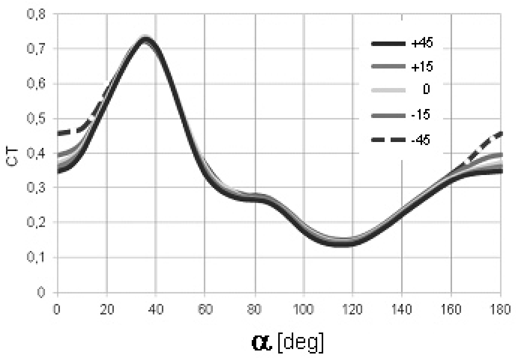


Fig. 6. Torque coefficient distributions for various bevel angles of the inner blade edge

There is a visible influence of the bevel angle on the instantaneous torque values at rotor rotation angles close to 0 degrees (and 180 degrees due to the symmetry of the Savonius rotor geometry). The length of the interval within which the torque coefficient changes can be observed is approximately equal to 30 degrees. The maximum change of the power coefficient C_P calculated from the formula:

$$C_P = \frac{P}{\frac{1}{2}\rho U^3 DH} \tag{2}$$

where P stands for power and the remaining symbols are identical to those in formula (1), was obtained for the case of the bevel angle -45 degrees and was equal to 0.20% as compared to the reference case with square blades, for the rotor rotation angle equal to 0 (or 180) degrees. The worst Savonius rotor performance characteristics were obtained for the bevel angle equal to + 45 degrees.

Another attempt to improve the Savonius rotor performance was bevelling outer edges of the blades (while keeping the inner edges square). The definitions and values of the examined outer bevel angles are shown in Fig.7, while the torque coefficient changes obtained as the result of bevelling are shown in Fig. 8.

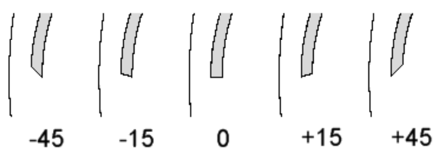


Fig. 7. Examined bevel angles of outer blade edge

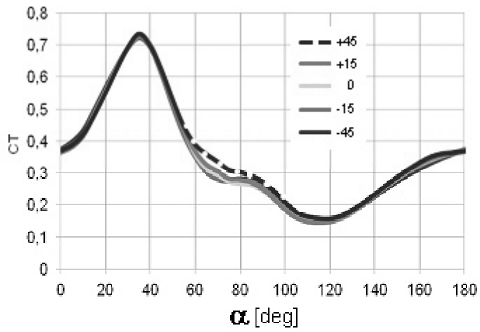


Fig. 8. Torque coefficient distributions for various bevel angles of the outer blade edge

Here again we can observe an interval, this time situated close to 90 degrees, within which the blade edge bevelling has visibly changed torque coefficient values. The most favourable C_T distribution was obtained for the bevel angle equal to +45 degrees. The power coefficient increase corresponding to the rotor rotation angle was equal to 0.17%. The worst performance characteristics were obtained for the bevel angle equal to -45 degrees, which means that the present tendency was opposite to that observed for inner blade edge bevelling.

Conclusion

The article presents the results of the numerical analysis of the flow inside the Savonius rotor, with particular attention being paid to the vicinity of the blade gap. The mechanisms controlling the flow through the gap was recognised as having the form of instantaneous vortex structures forming near the blade edges. The conclusions resulting from the flow analysis justified an attempt to improve the Savonius turbine performance via shaping rotor blade edges. The simplest way to do it was to bevel. Series of blades with either inner or outer bevelled edges were examined. The obtained results reveal certain potential for improving Savonius rotor performance.

The here presented analysis is the initial part of comprehensive studies oriented on improving characteristics of Savonius turbine performance by changing its geometry. The next direct step of this part of study will include a detailed analysis of the flow structure inside the rotor having the geometry modified in the above way to recognise the cause of the recorded torque improvement and optimise it in a controlled way.

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Е.Швирыдчук, К.Клюдзинска. Повышение эффективности ротора Савониуса посредством профилирования кромок его лопастей

В статье представлены результаты численного анализа течения внутри ротора Савониуса. Особое внимание уделено окрестности зазора между лопастями для того, чтобы изучить механизм управления потоком в этой области. На основе заключений, являющихся следствием исследования, созданы основные принципы, с помощью которых предпринята попытка повысить эффективность турбины Савониуса путем профилирования кромок лопастей ротора. В статье приведены отдельные типичные картины течения вблизи зазора между лопастями и результаты влияния профилирования кромок лопастей на флуктуации крутящего момента на половине периода вращения ротора.

Ключевые слова: *ротор Савониуса, зазор между лопастями, вихри, повышение эффективности.*

Е.Швіридчук, К.Клюдзінська. Підвищення ефективності ротора Савоніуса шляхом профілювання кромок його лопатей

У статті представлені результати числового аналізу течії всередині ротора Савоніуса. Особлива увага приділена околу щілини між лопатями для того, щоб вивчити механізм керування потоком у цій області. На засаді висновків, що є наслідком дослідження, створені основні принципи, за допомогою яких здійснена спроба підвищити ефективність турбіни Савоніуса шляхом профілювання кромок лопатей ротора. В статті приведені окремі типові картини течії поблизу щілини між лопатями та результати впливу профілювання кромок лопатей на флуктуації коливань крутильного моменту на половині періоду обертання ротора.

Ключові слова: *ротор Савоніуса, щілина між лопатями, вихрі, підвищення ефективності.*