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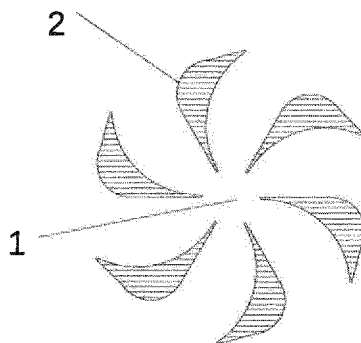
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DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
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MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
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Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

(54) Title: CROSS-FLOW TURBINE



Drawing 1:

(57) Abstract: The invention deals with cross-flow turbines meant to be immersed in undisturbed free fluid flow fields such as wind, tidal, river or shallow ocean wave flow, crossing perpendicularly the rotation axes of the turbine. The curved blades of the turbine are positioned at the turbine perimeter in such a way that the curved channels between the blades form S-shaped rotating ducts interrupted in the middle by the empty turbine throat (1). These turbines are multiduct extensions of the single duct Savonius turbine. In multiduct turbines at least one duct is all the time in a favourable position for producing strong cross-flow diametrically through the throat and high torque with greatly reduced variation versus rotation angle. The best performance is achieved, if the convex portion (2) of the boundary of each blade is located as far from the axes as possible.



Published:

- *with international search report (Art. 21(3))*
- *with amended claims (Art. 19(1))*

Cross-flow turbine

This invention considers methods and means for extracting mechanical energy from free flows such as wind, tidal, river or shallow ocean wave flows. The adjective free is used to exclude massive structures aiming at guiding the flow to the energy converter, typically represented by a turbine. The known free flow cross-flow turbines are rotors with their axes perpendicular to the free flow and equipped with a set of various types of blades at their perimeter. Their design is traditionally based on considering the effectiveness of a single blade in the energy conversion process. Thereby the total flow through the turbine via the entrance channels passing further across the inner volume near the rotation axes, appropriately called as the throat, and passing finally through the exit channels to outside of the turbine again has not received the attention it definitely deserves.

In wind turbine literature the cross-flow turbines are divided in two categories, namely to the lift type turbine [1] and to the drag type turbine, most typically represented by a classical wind speed meter with two hemisphere shaped cups drifting with the wind.. As to the Savonius turbine [2, 3] this division is inadequate, since the blades are not supposed to stop the cross-flow and let the turbine drift along the wind, but to guide the flow through the turbine along a doubly bent S-shaped path with minimal flow resistance. The throat of the Savonius turbine about the axes is connected by two curved guides to the outer space around the turbine. This configuration suffers from one basic problem. The desired cross-flow occurs two times per revolution only and is absent during the rest of the time. This means that useful flow energy is wasted and the variations in torque are large extending from the peak torque to a substantial negative torque.

One way to even out the torque variation is to twist the blades into spiral form. Thereby at each instant of time the optimum position to the wind is reached at a narrow layer along the turbine axes only. Therefore this solution solves the torque variation problem, but does not, however, improve the overall efficiency.

Extrapolation of the Savonius turbine into multibladed versions has been tried by many including Savonius himself. The problem of passing the cross-flow through the throat of the turbine near the rotation axes has not been solved satisfactorily. The throat of a multibladed turbine must contain no structures preventing or disturbing the

diagonal flow from any direction. This means that the inner ends of the blades of a multibladed version must point directly to the axes and extend only upto a reasonable minimum distance from the axes.

This invention aims at creating several doubly bent S-shaped ducts, with interrupted walls in the middle, through the turbine, at least one of which is allways lying in a favourable position for providing strong cross-flow and strong torque.

The cross-flow through the duct must be able to pass the rotor throat about the axes as undisturbed as possible, suggesting that the presense of any material axes should be avoided. The S-shaped cross-flow is best achieved, if the central cavity is connected to the turbine perimeter with several curved channels, separated fom each other by curved blades. If the number of the curved channels is chosen to be too small, the torque variation remains higher than desired. For too large number, on the other hand, the channels tend to become too narrow causing higher flow resistance than desired.

This invention consists of a set of well-defined S-shaped ducts from outside of the turbine traversing through the throat about the turbine axes and back to outside again. The key feature of this concept is that the innermost tips of the curved blades guide the main flow diametrically through the turbine throat to the opposite side curved exit section.

As the turbine rotates each curved channel passes repeatedly the sequence of twelve steps:

1	The most significant entrance channel
2	Decreasingly significant entrance channel
3	Marginal entrance channel
4	No-flow channel
5	Marginal exit channel
6	Increasingly significant exit channel
7	The most significant exit channel
8	Decreasingly significant exit channel
9	Marginal exit channel
10	No-flow channel
11	Marginal entrance channel
12	Increasingly significant entrance channel

The steps marked with grey are contributing to the power production, while the unmarked steps contribute nothing. With a multi-channel turbine about one half of the channels are at every instant relevant for power production and the other half is resting. Thus variations of the torque remain small. Moreover each channel contributes to the power production along the full axial length of the channel.

While the turbine rotates the multi-channel structure creates practically a stationary S-shaped cross-flow with one end of S pointing to up-wind and the other end to down-wind.

Drawing 1 illustrates a six-blade or three-duct turbine showing the throat (1), which is the empty space about the axes, and the six curved blades, each having a convex and a concave boundary. The convex portion (2) of the blade boundary is lying as far as possible from the axes and has small radius of curvature for achieving marked underpressure at the convex boundary and generating high torque.

[1] US patent 1,835,018[

[2] US patent 1,697,574

[3] Sigurd J. Savonius The wing-rotor in theory and practice, Helsingfors

Claims

1. Cross-flow turbine to be immersed in a free flow field such as wind, tidal flow, river flow or shallow ocean wave flow with the rotational axes of the said turbine lying perpendicularly to the flow direction and having more than two regularly spaced curved blades , recognized from

that the blades extend from the perimeter of the turbine down to reasonably close, but not too close to the rotation axes and that the blades are positioned so that the curved entrance flow channel between two neighbouring blades with favourable orientation relative to the incoming flow guides the main cross-flow diametrically through the throat (1) of the turbine inside the inner tips of the blades to the opposite side curved exit flow channel or channels so that the main flow from outside, through the turbine, back to outside again follows preferably with minimal flow resistance an essentially stationary S-shaped cross-flow path almost irrespective of the rotor's angular position.
2. The turbine according to claim 1. recognized from

that the convex boundary of each blade includes a convex portion (2) with small radius of curvature located as far as possible from the axes.

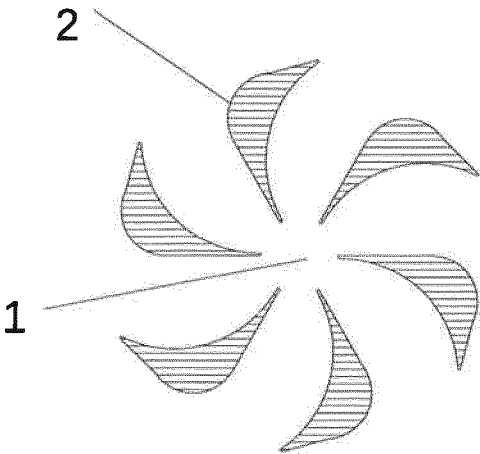
AMENDED CLAIMS**received by the International Bureau on 18 September 2018 (18.09.2018)**

1. Cross-flow turbine of cylindrical shape to be immersed in free wind or tidal, river or shallow coast ocean wave flows, which cross the turbine axes perpendicularly with the said turbine having n blades, where n is larger than 2, arranged in n -fold rotational symmetry,
r e c o g n i z e d from

that the blades are rigid cylindrical blades comprising a smoothly curving circular arc within a fairly large angular range about 90 degrees and that a planelike extension is joined tangentially and smoothly to one end of the arc and that the blades are positioned in such a way that the planelike extension of each blade is pointing directly to the rotation axes and that the minimum distance of the blades from the axes is chosen large enough for allowing unhindered cross-flow through the turbine in any direction.

2. Cross-flow turbine according to claim 1, r e c o g n i z e d from

that the planelike extension section of the blades is absent, but the tangential plane at the inner end of the mean circular arc running about halfway between the convex and concave faces of each blade is pointing directly to the rotation axes and that the minimum distance of the blades from the axes is chosen large enough for allowing unhindered cross-flow through the turbine in any direction



Drawing 1:

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2018/000010

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F01D, F03D, F03B, E02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base, and, where practicable, search terms used)

EPODOC, WPIAP

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4362470 A (LOCASTRO GERLANDO J et al.) 07 December 1982 (07.12.1982) whole document, especially abstract; column 2, lines 29-58; column 3, lines 11-61; figures 1-3	1, 2
X	US 2012119500 A1 (CHRISTOPHER THEODORE J [US]) 17 May 2012 (17.05.2012) whole document, especially abstract; pages 3 and 4; figures 1-11 and 13A-13C	1, 2
X	CH 706919 A2 (BINYET EMMANUEL [CH]) 14 March 2014 (14.03.2014) whole document, especially abstract; paragraphs [0004]-[0016]; figures 1-10	1, 2

☐ Further documents are listed in the continuation of Box C.
☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

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Date of mailing of the international search report

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CLASSIFICATION OF SUBJECT MATTER

IPC

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E02B 9/08 (2006.01)

INTERNATIONAL SEARCH REPORT
Information on Patent Family Members

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PCT/FI2018/000010

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
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		AU 2011326231 B2	20/10/2016
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