Ideas about a 4-buckets Savonious rotor called the VIRYA-1.45 for driving a positive displacement pump

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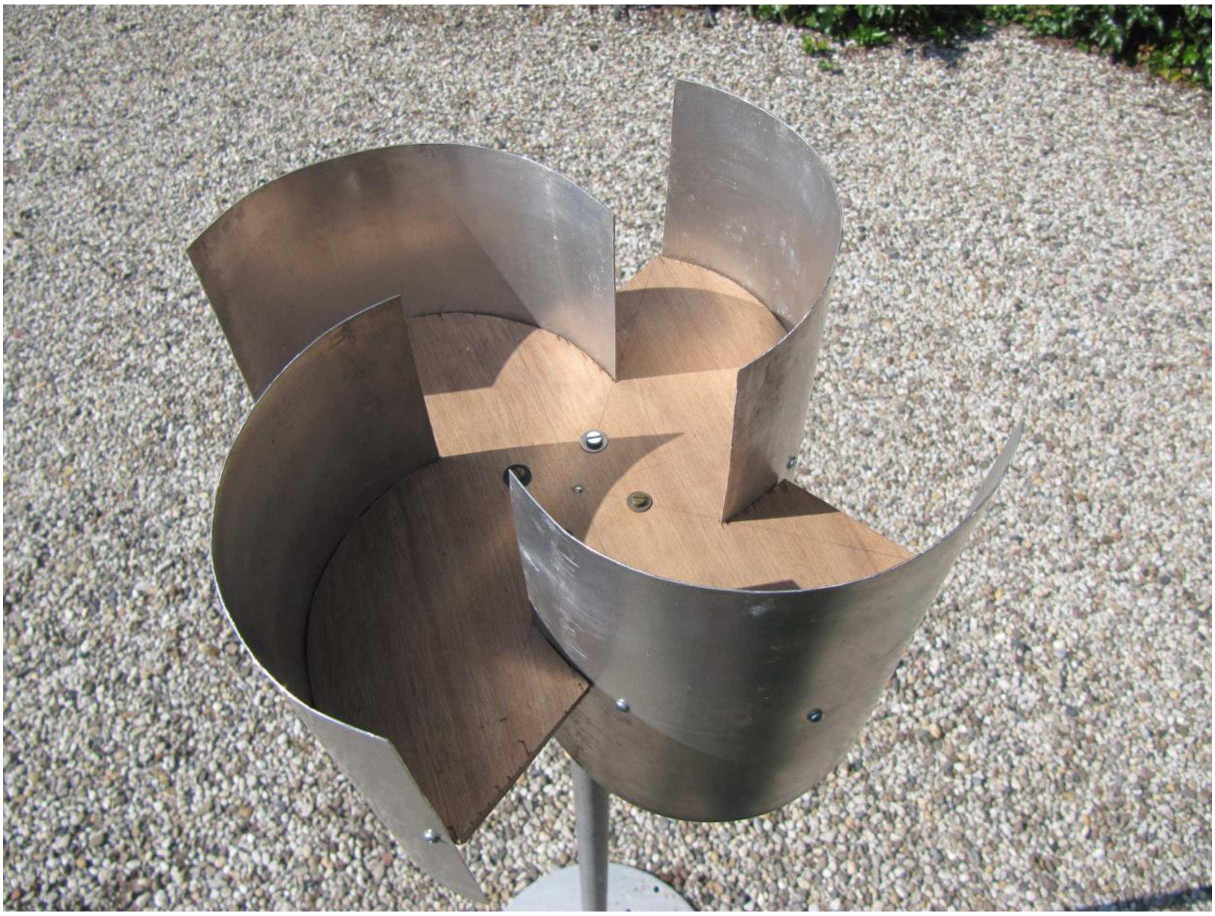
The idea of this rotor can be used by anyone but the VIRYA-1.45 rotor or a proper scale model of it has not yet been built and tested. Especially because the windmill has no safety system, no responsibility is accepted by Kragten Design by use of this rotor.



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1 Introduction

A normal Savonious rotor is a vertical axis wind turbine (VAWT) with two buckets made out of a half cylinder. The cylinders have a certain overlap and this overlap allows an internal flow through the rotor. Because of this internal flow, a Savonious rotor is not a pure drag machine but during a part of a revolution it also works as a lift machine. Therefore it has a higher maximum C_p than a pure drag machine. Information about pure drag machines is given in my public report KD 416 (ref. 1). Information about measurements on Savonious rotors available on the Internet is given in my public report KD 599 (ref. 2).

The starting torque of a normal Savonious rotor depends very much on the position of the buckets with respect to the wind direction. The starting torque is maximal if the buckets are perpendicular to the wind and almost zero if the buckets are in line with the wind direction. Several methods are used to solve this problem. The most common method is to use two Savonious rotors on top of each other which are 90° rotated with respect to each other. Such a Savonious rotor is also called a 2-phase Savonious rotor. Another option is to give the blades a 90° twist but manufacture of such blades is rather difficult. One has also tried to make Savonious rotors with three buckets but those rotors have a very low maximum C_p because there is almost no flow through the rotor. There is certainly no flow at all if the three buckets touch each other at the centre of the rotor.

Some time ago the idea came up to design a Savonious rotor with four buckets and to do it such that there is enough space in the centre of the rotor for an internal flow. The starting torque will fluctuate only a little if four buckets are used. The rotor will therefore have a high starting torque coefficient and will therefore be able to drive a positive displacement pump. As the rotor has a vertical axis, the pump can be coupled directly to the rotor axis if the correct pump type and pump geometry is chosen. Selection of the correct pump is out of the scope of this report. For generation of electricity, I will always advice to use a horizontal axis wind turbine (HAWT) as such a wind turbine uses much less material for a certain power.

2 Description of the rotor of the 4-buckets Savonious rotor

An important point for the rotor geometry is optimal use of materials. It was chosen to use stainless steel or galvanised steel with dimensions 1000 * 1000 * 1 mm for one bucket. So two sheets of 1 * 2 m are needed for four buckets. A sheet is cambered such that it covers an angle of 135° (the bucket of a normal Savonious rotor covers an angle of 180°). Because of the 135° angle, there is a square area in the heart of the rotor where there are no buckets. The camber radius r for a sheet length l can be calculated by the formula:

$$r = l * 360 / (2\pi * 135) \quad \text{(mm)} \qquad (1)$$

Substitution l = 1000 mm in formula 1 gives that r = 424.4 mm. The square area in the centre of the rotor has sides with a width of 424.4 mm. These sides make an angle of 45° with the lines through the tips of the buckets. The distance a in between the corner of the square area and the heart of the rotor is therefore $424 / \sqrt{2} = 300.1$ mm. For the rotor radius R we therefore find that $R = r + a = 424.4 + 300.1 = 724.5$ mm. The rotor diameter D is two times R and so $D = 2 * 724.5 = 1449$ mm. This is at the heart of the 1 mm thick sheet. So at the outside of the sheet, the diameter D is 1450 mm = 1.45 m and the rotor is therefore called the VIRYA-1.45. The rotor has a height H of 1000 mm = 1 m and the swept rotor area A is therefore $1 * 1.45 = 1.45$ m^2. The total blade area is 4 m^2 so the solidity is $4 / 1.45 = 2.759$.

The four buckets are connected to each other by one 18 mm thick water proof plywood sheet which is mounted just half way the height of the rotor. Two sheets can be made out of a standard sheet size 1.22 * 2.44 m. Each blade is connected to the sheet by a large number of stainless steel screws. A top and a side view of the rotor are given in figure 1.

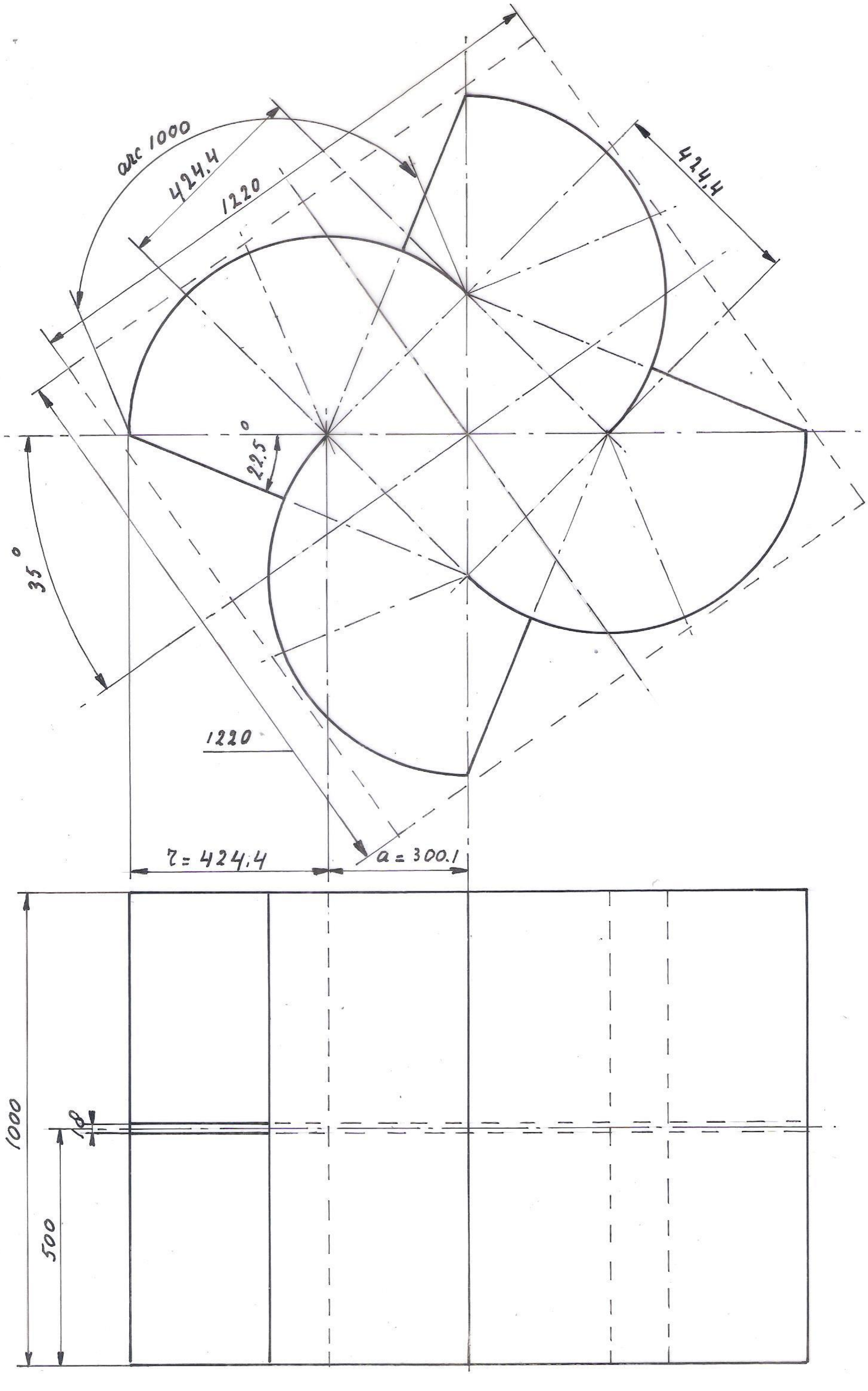

Figure 1 Sketch of the VIRYA-1.45, 4-buckets Savonious rotor

In stead of a plywood sheet one can also make a construction of bended and welded strips. Another option is to use a plywood sheet at the top and at the bottom of the rotor. This will result in a higher maximum C_p because the tip losses will be less. However, now the tower pipe will end at the bottom sheet of the rotor and the bending moment in the rotor shaft will be much larger than for a tower pipe which ends half way the rotor height.

This windmill has no safety system which limits the rotational speed and the rotor thrust at high wind speeds. So this windmill can only be used at sites where very high wind speeds simply don’t occur or if the whole windmill is laid down in case of a heavy storm warning!

3 Determination of the rotor characteristics

The aerodynamic theory which is given in my public report KD 35 (ref. 3) for HAWT’s can’t be used to predict the characteristics of this 4-bucket Savonious rotor. The best way is to make a scale model and test it on front of the open wind tunnel like the one of the University of Delft. However, these tests will be rather expensive if the wind tunnel has to be hired. Another way is to test a scale model in the open air.

Assume the original rotor is scaled down with a factor 2. This means that now the buckets are made of sheet size 500 * 500 * 0.5 mm and that the plywood sheet is made from a sheet size 610 * 610 * 9 mm. So now the rotor diameter D is 0.725 m and the rotor height H = 0.5 m. The swept rotor area A is now 0.3625 m^2.

I have measured a Chinese axial flux PM-generator for which the characteristics for 12 V battery charging are given in public report KD 595 (ref. 4). Assume that this generator is used to test a scale model of the VIRYA-1.45 rotor. The plywood sheet is connected to the generator housing by six bolts M8 at a pitch circle of 65 mm. It isn’t sure if the maximum torque level of this generator is high enough to load the rotor strong enough but at least some information about the behaviour can be gained. If the generator appears to be not strong enough, one has to take a bigger one. Kragten Design will perform no tests for this windmill.

The photo on the front page is from a very simple scale model scale 1 : 5 using 0.8 mm thick aluminium blades. I have tested this rotor on a bicycle. The rotor runs nicely unloaded but this says nothing about its characteristics.

4 Alternative 4-buckets Savonious rotor with smaller blades and a larger rotor diameter

The rotor as described in chapter 2 has stainless steel or galvanised steel blades size 1000 * 1000 * 1 mm. Every blade has a mass of about 7.8 kg and the total mass of all four blades will therefore be about 31.2 kg which is a lot for a rotor with a diameter of 1.45 m and a height of 1 m. Stainless steel is expensive but even for galvanised steel, this rotor will be rather expensive. The new idea is to use sheets size 500 * 1000 * 1 mm. So four blades can now be made out of one standard sheet size 1 * 2 m. The same square plywood sheet size 1220 * 1220 * 18 mm will be used to connect the blades to the hub.

The original blades were cambered over 135°. The new smaller blades will be cambered over 105°. The bending radius r can be calculated as $r = 500 * 360 / (105 * 2 * \pi) = 273$ mm. As the bending radius is smaller than for the original rotor, the blades can be shifted more to the corners of the square plywood sheet. This results in a larger rotor diameter of about 1600 mm and the windmill with this alternative rotor is therefore called the VIRYA-1.6.

An advantage of the smaller blades is also that less material has to be removed from the plywood sheet. Smaller blades make also that the flow through the rotor has a larger cross sectional area to pass. This larger cross sectional area and the somewhat larger rotor diameter will partly compensate the smaller blade area and so the generated power will be more than half the generated power of the original rotor. The real maximum C_p, the real optimum tip speed ratio λ_{opt} and the real starting torque coefficient C_{qstart} can only be found if measurements are performed in an open wind tunnel for which there is no tunnel blockage.

A sketch of the alternative Savonious rotor is given in figure 2.

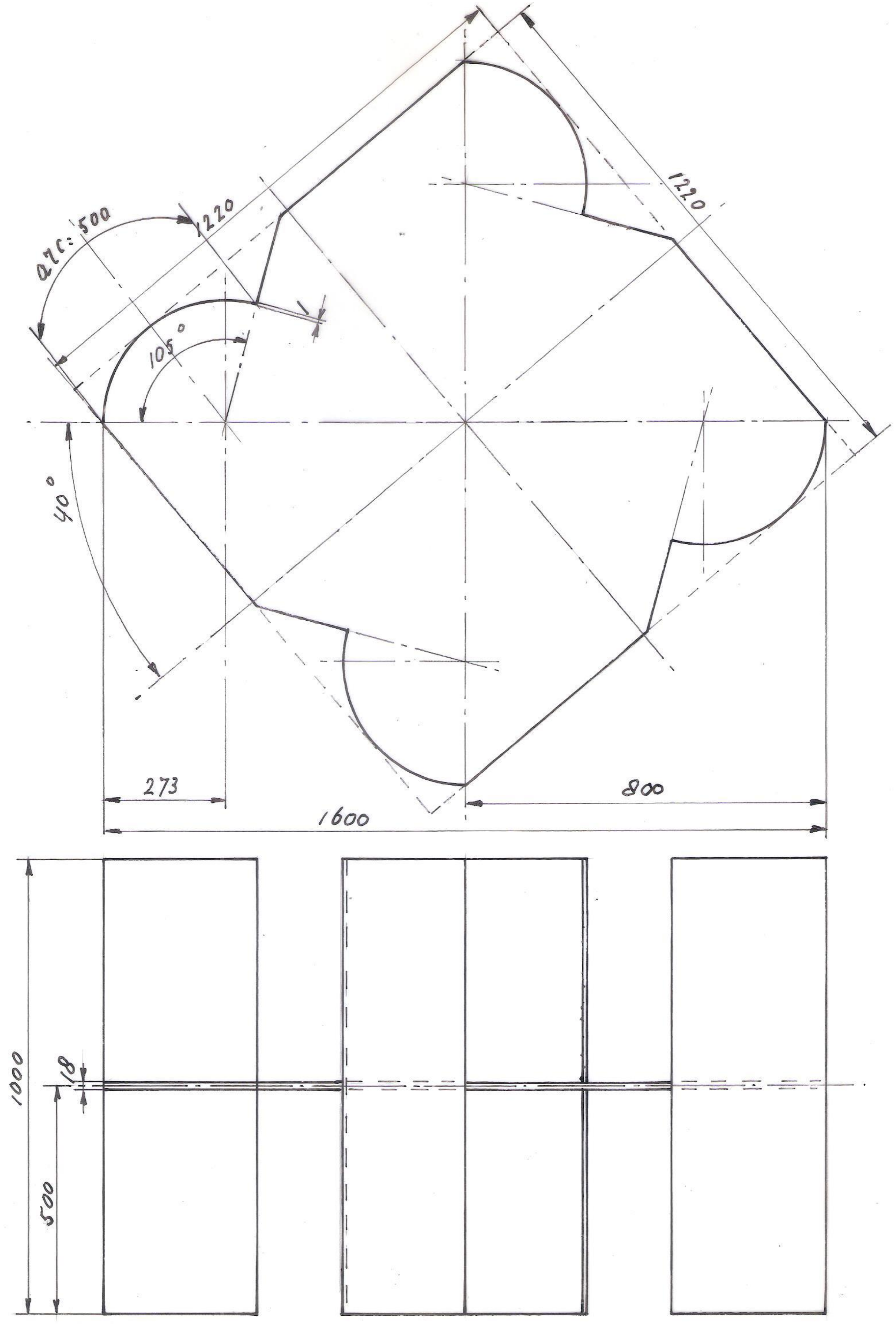

Figure 2 Alternative VIRYA-1.6, 4-buckets Savonious rotor with smaller blades

5 References

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