The rotating blade, vertical axis wind turbine

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1 Introduction

To propel the blades of a windmill, one can use the aerodynamic lift force or the aerodynamic drag force. The lift force L is the force (in N) which is generated on an airfoil perpendicular to the relative wind speed W. The drag force D is the force (in N) which is generated on a drag body in the direction of the relative wind speed W. The relative wind speed W is the wind speed (in m/s) which is felt by the airfoil or by the drag body. Modern horizontal axis wind turbines make use of the lift force and the blades move in a direction perpendicular to the undisturbed wind speed V (in m/s). Information about horizontal axis windmills can be found for instance in my report KD 35 (ref. 1).

Vertical axis wind turbines can make use of drag, lift or a combination of drag and lift. A common type of a drag machine is a cup anemometer which is normally used for measuring wind speeds. Pure drag machines have several disadvantages of which the most important is that the maximum power coefficient C_p is very low. An analysis of pure drag machines is given in my public report KD 416 (ref. 2).

A well known type of a vertical axis wind turbine using a combination of drag and lift is the Savonius rotor which is made of two halve cylinders. A well designed Savonius rotor has a higher optimum tip speed ratio λ of about 1 and a higher maximum C_p of about 0.2 than a pure drag machine.

A well known type of a vertical axis wind turbine using lift is the Darrieus rotor. The original Darrieus rotor has blades which are curved like the shape of a hanging chain. However, there are also Darrieus rotors with straight blades or with blades with a helical twist. A Darrieus rotor has as main advantage that it functions independent of the wind direction. However, it has also a lot of disadvantages. A disadvantage of a Darrieus rotor is that it has a negative starting torque coefficient and so a motor is needed to start the rotor. Advantages and disadvantages of Darrieus rotors are given in public report KD 215 (ref. 3).

The blades of a Darrieus rotor with straight blades can be moved during one revolution of the rotor. This in done for instance in the Gyromill. This cyclic movement of the blades results in a positive starting torque coefficient. However, a disadvantage is, that now a vane is needed which is connected to the centre of the cyclic mechanism for correct orientation of the rotor to the wind direction. This principle is for the first time used in the Voith Schneider ship propulsion. It was already patented in 1931. A very nice description of the functioning of the Voith Schneider system is given on www.voithturbo.de/545950.htm

Another way to realise a positive starting torque coefficient is to rotate the blade over halve a revolution for one complete revolution of the whole rotor. This system is less well known than the Voith Schneider system but I know that it has been invented by several people independent of each other. I invented this idea already in about 1975 and I have made a prototype of this system with a rotor with 4 blades. This prototype had a horizontal axis, because in this way it was easier to manufacture but the system was originally meant for a vertical axis wind turbine. A photo of the prototype is given on figure 9.11 on page 210 of the (Dutch) Windwerkboek (ref. 4). A copy of the photo is given in figure 1. The system is activated by a combination of drag and lift when it rotates at a low tip speed ratio but it is activated almost completely by lift when it runs at a moderate tip speed ratio. It also needs a vane for correct orientation of the rotor to the wind direction.

This rotating blade windmill is also described in figure 2.3 b on page 16 of the dictation Windenergie, dictaatnr. 3.323 of the University of Technology Eindhoven (ref. 5). A copy of figure 2.3 b is given in figure 2. On 21-03-2014, I had a discussion on the renewable energy fair in Husum in northern Germany with someone of the German company NTWS wind systems GmbH about a rotating blade windmill with five blades which this company has invented. They have obtained a patent about this system and a patent about the mechanism which drives the blades. To my opinion the patent for the system has been given unfairly because this system is known already for a long time.

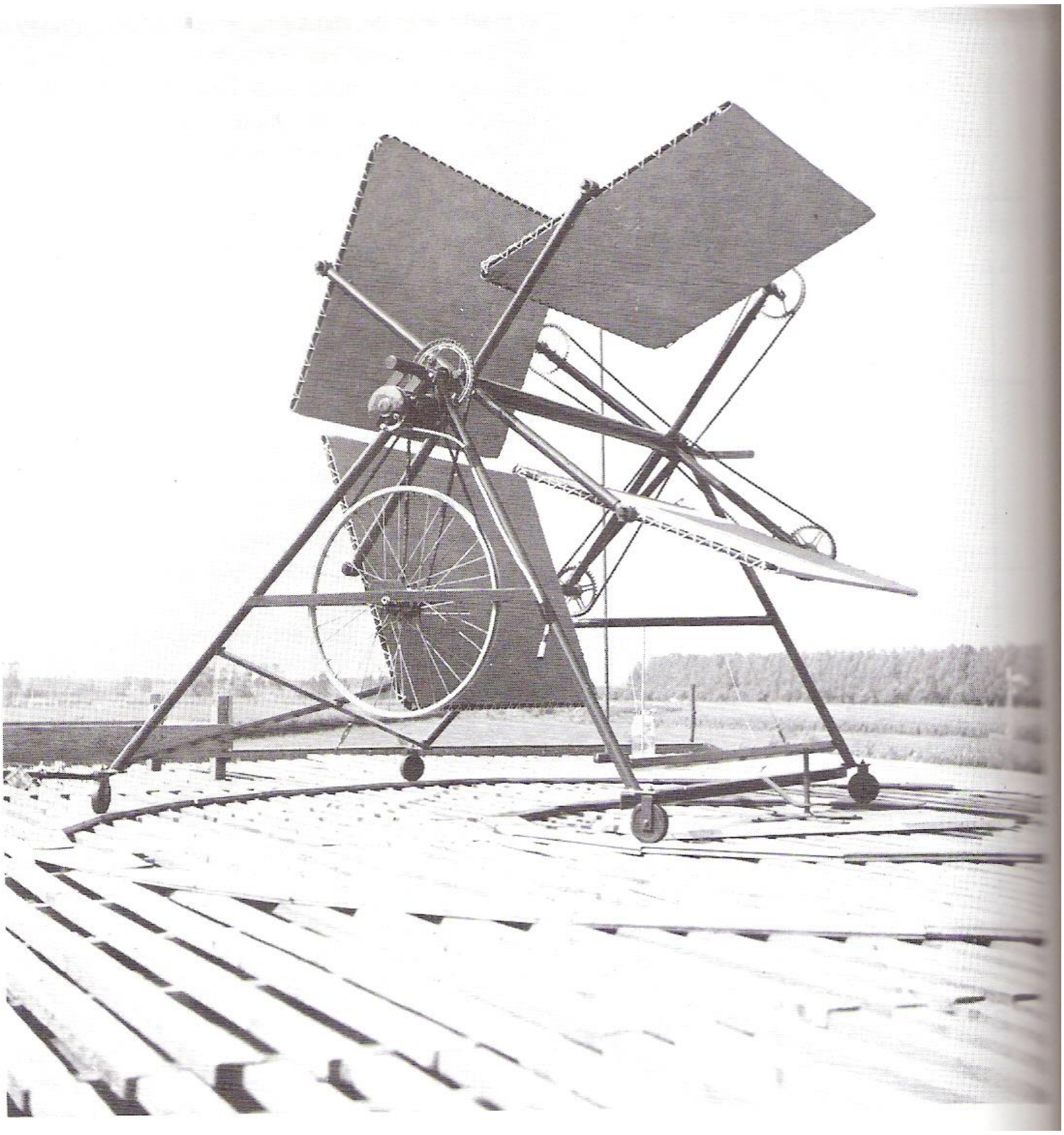

fig. 1 Copy of figure 9.11 on page 210 of the Windwerkboek (ref. 4)

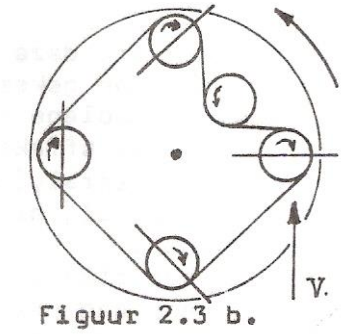

Fig. 2 Copy of figure 2.3 b on page 16 of dictation Windenergie (ref. 5)

2 Description of the rotating blade system

A rotor equipped with the rotating blade system can have one, two, three, four or more blades. I think that with only two blades, a good working rotor can be made. The main advantage of this system is the high starting torque coefficient. This is important if the windmill is driving a load with a high starting torque like a positive displacement pump. For generation of electricity, a high starting torque coefficient is not important and in this case I think that one can better use a horizontal axis wind turbine.

The system will be described for a rotor with only one blade. A rotor with only one blade can be seen as an art object. If it runs unloaded, it demonstrates the functioning of the system very nicely if both sides of the blade have a different colour.

The windmill has a tower with a height in between 6 and 12 m. On the top of the tower there is a bearing housing in which the rotor is rotating. A vertical shaft is rotating in the centre of the tower. The upper part of this shaft is directly connected to the rotor. The lowest part of the shaft is connected to the load. The rotor is made of a horizontal pipe and at the longest end of this pipe there is a vertical bearing housing in which the rotor blade can rotate. On the shortest side of the horizontal pipe there is a balancing weight.

The rotor blade is divided in an upper part which is situated above the bearing housing and a lower part which is situated below the bearing housing but both parts have the same orientation and are mounted to the same shaft. This construction prevents twist of the horizontal pipe and limits the bending moment in the blade shaft for a certain total blade area.

Situated above the horizontal pipe of the rotor, there is a vane arm with on one long end a vane blade and on the other shorter end a second balancing weight. This vane arm has the same axis of rotation as the rotor.

The vane shaft and the blade shaft are connected to each other by a transmission with a gear ratio 1 : 2. Because of this gear ratio, the blade makes half a revolution for one revolution of the rotor if the vane arm has a fixed position. For the transmission of the prototype which I made in 1975, I used chains and chain wheels. But chains are wearing rather fast if they move in the open air, so a chain transmission is not advised. It might be better to use a toothed belt transmission or may be even two rectangular gear boxes with a rotating shaft in the horizontal pipe. Up to now, a toothed belt transmission is chosen. The small belt wheel on the vane shaft and the large belt wheel on the blade shaft are positioned such that the belt is running in the horizontal pipe of the rotor. For this pipe it might be easy to use a rectangular one with the large sides horizontal

The belt wheel on the vane shaft is positioned such that the blade is parallel to the vane arm if it is at position 1 (see figure 3). In figure 3, the blade is drawn for 12 positions of the rotor which differ 30°. Because of the gear ratio 1 : 2, the blade rotates only 15° for 30° rotation of the rotor. So for 180° right hand rotation of the rotor, the blade has rotated 90° right hand which means that it is perpendicular to the wind direction for position 7.

2.1 Rotor not rotating

The first situation which will be observed is when the rotor is not rotating. This can be realised by locking of the vertical shaft. For position 1, the blade is parallel to the wind direction. So no lift L is created. Only a very little drag D is created because the blade is very slender.

For position 4 the blade makes an angle of 45° with the wind direction. So for this angle lift and drag will be created. The component of the lift in the direction of rotation of the blade minus the component of the drag against the direction of rotation results in a tangential component which supplies a certain torque. The same situation exists at position 10.

For position 7 the blade makes an angle of 90° with the wind direction. So for this angle no lift and only drag will be generated. The drag will be rather high because the relative wind speed W is the same as the wind speed V.

For the positions 2 and 12 it might be the case that the tangential component of the drag is larger than the tangential component of the lift so that these positions may have a negative influence on the starting torque. But to determine this, one needs aerodynamic characteristics of the airfoil used for the blade.

For the remaining positions 3, 5, 6, 8, 9 and 11, the final tangential force will also be the result of lift and drag components in the direction of rotation like it is the case for position 4 and 10. So all positions except position 1 and possibly 2 and 12 contribute to the starting torque and this is why the rotor will have a rather high starting torque coefficient, even if it has only two blades.

2.2 Rotor running unloaded

In the first instance we only look at the blade in position 7. If the rotor is running unloaded, the blade speed U will be the same as the undisturbed wind speed V. So we assume that the speed U of the rotor at the blade axis will be the same as V.

Next we investigate what happens at the remaining blade positions. First we only look at positions 1, 2, 3, 4, 5 and 6. The relative wind speed W with respect to the blade is found by vector adding U and V. The vectors V, U and W are also given in figure 3.

For position 1 we find that W = 2 * V and that the direction of W is parallel to the blade so no lift and only a little drag is generated. For position 7 we find that W = 0 and so no lift and no drag is generated. W is decreasing for increasing position number but for all positions W is just parallel to the blade and so no lift is created. As W is parallel to the blade and as the blade is very slender only very little drag will be generated. This means that the rotor will rotate unloaded with a rotational speed U which is very close to the undisturbed wind speed. The vector graphs for these positions are also given in figure 3.

For position 8 we will find a similar graph as for position 6 except that the direction of W with respect to the blade is opposite. The same counts for position 9 and 5, 10 and 4, 11 and 3 and 12 and 2. Because of the opposite direction of W at the front and at the back side of the rotor, we can’t use normal airfoils. The airfoil must be symmetric along two shafts. I think that a slender ellipse is the best choice but an airfoil in the shape of a canoe might also work. The airfoil must have a certain thickness in the middle to make it strong enough and to connect it to the blade shaft.

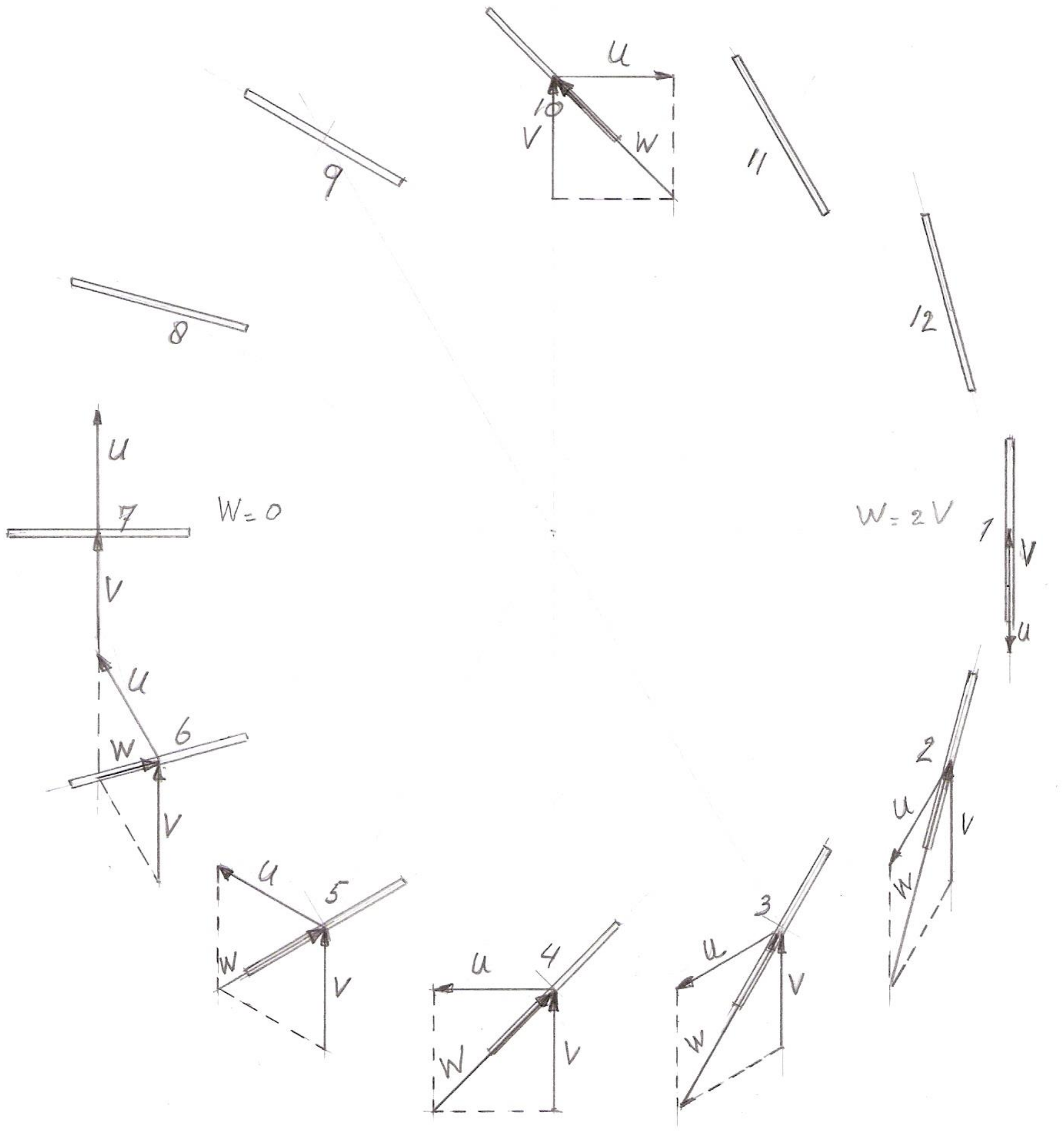

fig. 3 12 positions of the blade and unloaded vectors V, U and W for positions 2, 3, 4, 5 and 6

2.3 Rotor running at the estimated optimum tip speed ratio λ = 2/3

The tip speed ratio λ is defined as U / V. Extraction of energy from the wind will result in reduction of the undisturbed wind speed V till a certain lower value at the rotor plane. For horizontal axis wind turbines, the wind speed at the rotor plane is about 2/3 V if maximum power is extracted from the wind. For the rotating blade vertical axis wind turbine, there will be also some reduction of the wind speed at the rotor but the situation is more complicated because there is not one rotor plane if we have a rotor with more than one blade. If we have a rotor with two blades and if these blades are standing in position 1 and 7 one can say that they are standing in one plane. But if they are in position 4 and 10, we have two rotor planes behind each other and this means that if the blade at position 4 takes energy from the wind, the blade at position 10 will feel a lower wind speed.

So calculations for a reduced wind speed at the rotor are difficult and for the time being it is therefore assumed that the wind speed is not reduced. So the wind speed at every blade and at every position is assumed to be equal to the undisturbed wind speed V. The description is now given for a rotor with only one blade and only one blade will not extract very much energy from the wind so the assumption that the wind speed at the rotor is V, will be close to the reality.

In chapter 2.2 it has been shown that the unloaded tip speed ratio will be about 1. So one can extract only energy from the wind if the tip speed ratio is smaller than 1. So U must be smaller than V. U should not be taken very much smaller than V because this will result in a large angle of attack α in between the direction of W and the direction of the airfoil. If α becomes too large, the airfoil will stall and stalling results in a strong increase of the drag-lift ratio and therefore in a strong increase of the tangential component of the drag. For both the upper and lower part of the blade, a square plate is chosen because a square plate stalls only at an angle of attack of about 40°. Aerodynamic characteristics of a square plate are given in report KD 551 (ref. 6).

I have played a little with the value of λ and found that $\lambda = 2/3$ is a good first choice. So this means that U = 2/3 V. The vector diagrams for $\lambda = 2/3$ are given in figure 4 for positions 2, 3, 4, 5, 6 and 7.

The values of α found in figure 4 are given in table 1. The values of W found for these positions are also given in table 1. The lift coefficient C_l increases normally about linear to α for a symmetric airfoil. The lift L is proportional to the product of $C_l * W^2$ and so to the product of $\alpha * W^2$. The product $\alpha * W^2$ is also given in table 1. The drag is neglected at this moment because the angles α are rather small (except for position 7). In figure 4, lift values L are drawn perpendicular to W on a certain scale. The tangential component of L is also given in figure 4 and in table 1 and it can be seen that tangential component of L is maximal for position 5. But the tangential component of the lift contributes to the torque for all five positions. Only for position 7 it is the drag which supplies the tangential component. So the rotating blade vertical axis windmill is mainly a lift machine. More research is required to estimate what maximum C_p can be realised for this wind turbine concept.

position	α (°)	W (mm)	$\alpha * W^2$	(mm)	tangential component of L
2	2.5	48.5	5881	29.4	9
3	6.2	44	12003	60.0	35
4	10.5	36	13608	68.0	55.5
5	18.1	26	12236	61.2	60
6	34.0	16	8704	43,5	40.5

table 1 Values of α, W and $\alpha * W^2$ as a function of the position

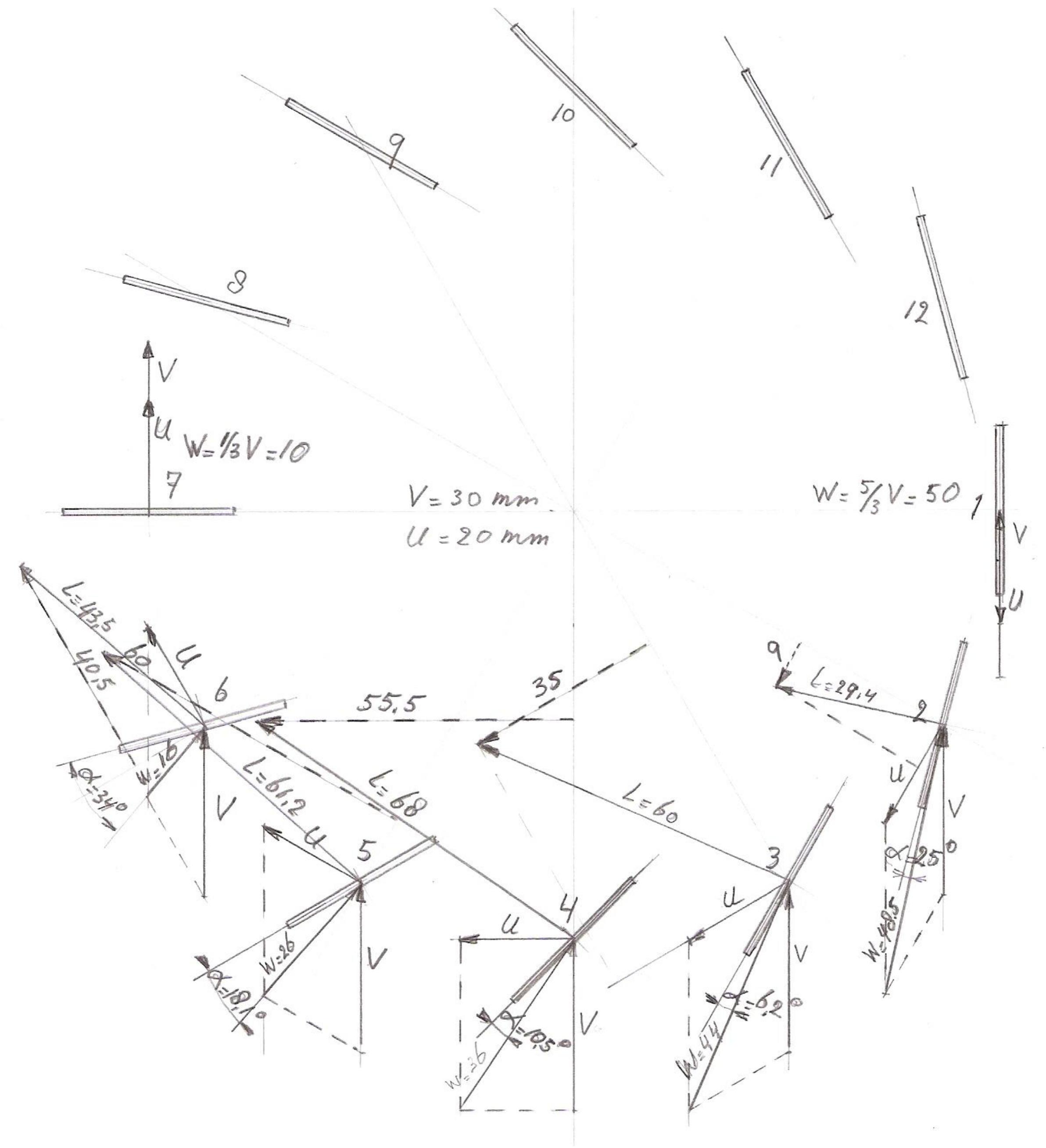

fig. 4 Determination of the tangential components of L for λ = 2/3 for positions 2, 3, 4, 5 and 6

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