Manual of

electricity generating windmill

VIRYA-1.04

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1 Introduction

In this manual the 3-bladed VIRYA-1.04, electricity generating windmill, is described. The generator of this windmill is made of a Shimano Nexus hub dynamo type DH-2R40 or another type with similar flange dimensions. It is expected that, together with the detailed drawings, the windmill can be manufactured in a simple workshop. The drawings of the VIRYA-1.04 windmill are numbered 1301-00, 1301-01 and 1301-02.
Drawing 1301-00 gives the assembly top and front view, details of the hinge, the blade connection, the clamps, the head bearings and a list with standard parts (indicated with --N).
Drawing 1301-01 gives the rotor blade (01), the vane blade (02) and the dynamo (01N).
Drawing 1301-02 gives the vane arm assembly (03), the clamp (04), the threaded rod (05) and the tower pipe (06).
Drawing 1302-01 gives a press with five pressing blocks for cambering of the blades.
Drawing 1303-01 gives the torsion tools and tools for pressing of the head bearings.

For the hand made drawings, originally paper size A3 was used. The drawings are first reduced to size A4 and than scanned to make them digital. The digital drawings are added to this manual in the appendix at chapter 7. The scale given on the digital drawings is not correct because of the reduction.

For the stainless steel blades of other VIRYA-windmills, hydraulic blade presses were developed. The aluminium blades of the VIRYA-1.04 rotor need a much lower pressing force and therefore a simpler, lighter and cheaper blade press is developed for the VIRYA-1.04 blades for which the cambering force is supplied by five pressing blocks and ten bolts M10.

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The rotor calculations of the VIRYA-1.04 are given in report KD 518 (ref. 1). Although the VIRYA-1.04 windmill has been designed carefully, no responsibility is assumed for the operation of the windmill as a whole, nor for any of its separate parts. Ten VIRYA-1.04 windmills were built by ten students of the University of Technology Twente during a course in the weekend of 26 – 28 April 2013. The course was given by me and was organised by the student society WOT. Some modifications have been made afterwards and for future windmill projects one should use this reviewed manual and the drawings dated 1-5-2013.

2 Specification

Diameter	D = 1.04 m
Number of blades	B = 3
Design tip speed ratio	$\lambda_d = 3.5$
Gear ratio	i = 1
Rotor eccentricity	e = 0.09 m
Tower height for tower pipe only	H = 1 m
Mass including 1 m tower pipe	m = 4.85 kg
Starting wind speed	$V_{start} = 2.6$ m/s
Survival wind speed	$V_{surv} = 30$ m/s
Cut in wind speed (if started)	$V_{cut\ in} = 2$ m/s
Rated wind speed	$V_{rated} = 8$ m/s
Nominal voltage	12 V DC
Power at rated wind speed	P = 6 W

3 The safety system (see drawing 1301-00)

The safety system was developed by A. Kragten in 1982. It is used in all VIRYA windmills developed by Kragten Design, in the water pumping windmill CWD 2000 and in some other windmills. A detailed description of the system for rotors with 7.14 % cambered blades can be found in the report KD 223 (ref. 2). A rough description is given in the free report KD 485 (ref. 3). Here only the use and working of the system in general will be explained.

At low wind speeds, the vane blade hangs in an almost vertical position and the moment of the horizontal component of the aerodynamic force on the vane $F_{v\ hor}$ around the tower axis is in balance with the moment of the thrust on the rotor F_t (see figure 1). The head and vane geometry are chosen such that the rotor is about perpendicular to the wind for low wind speeds. If the wind speed increases, the vane blade turns from an almost vertical to an almost horizontal position, because the moment of the aerodynamic force around the vane axis must be in balance with the moment of the weight G of the vane blade.

The horizontal component of the aerodynamic force on the vane blade at a certain wind speed is much smaller for the vane in the horizontal position than for the vane in the vertical position. This effect becomes dominant if the wind speed is higher than about 5 m/s and will result in yawing of the rotor of about 30° out of the wind as the wind speed increases from 5 m/s up to 8 m/s. At higher wind speeds the vane blade is lifted more and more and will be in a nearly horizontal position at wind speeds of about 30 m/s. At this wind speed the rotor is about 75° out of the wind. The rotor speed will be about constant for wind speeds between 8 m/s and 30 m/s. These are the values for a 1.5 mm aluminium vane blade.

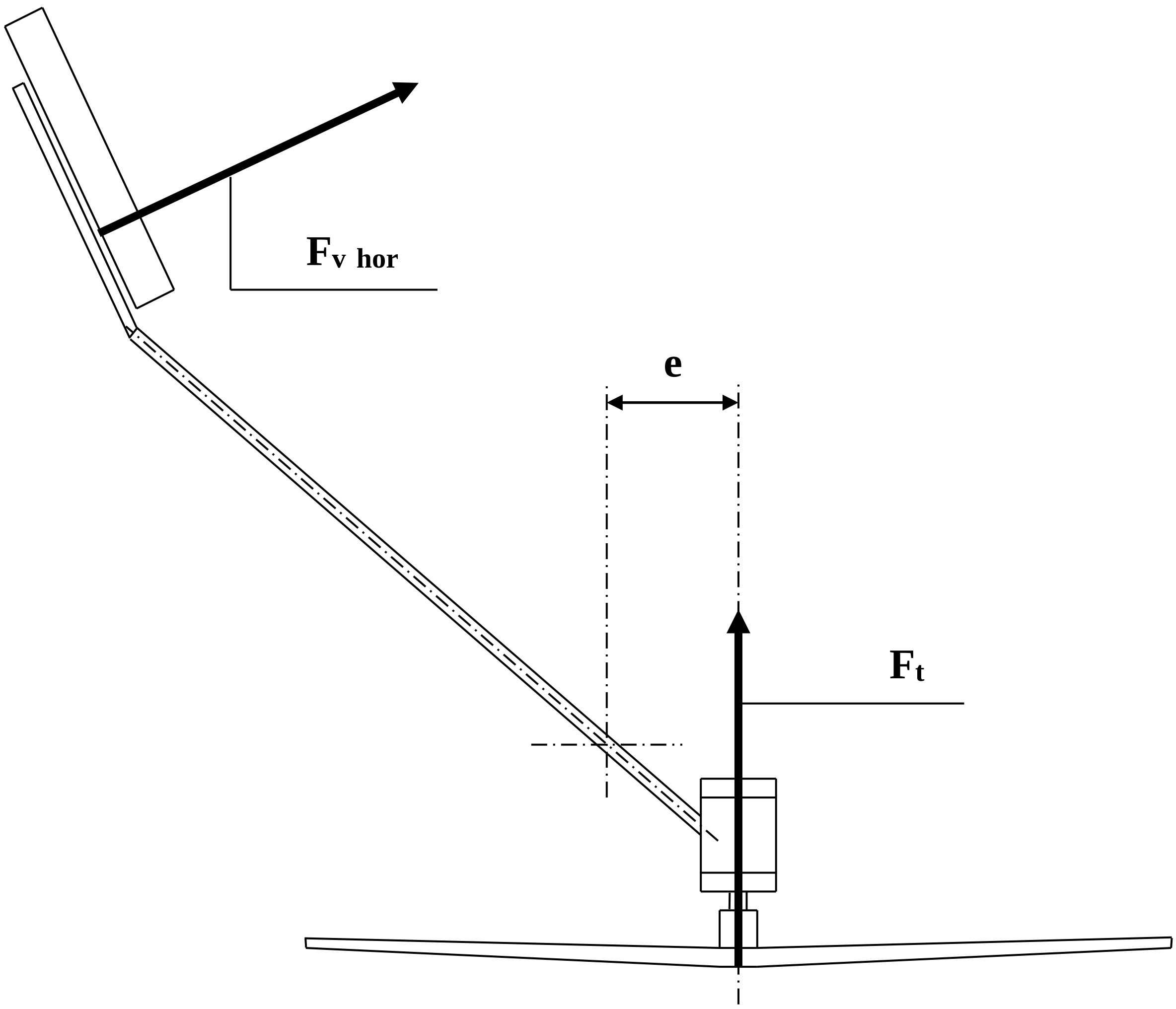


Figure 1 The hinged side vane safety system

The behaviour of this system is very stable and it has the following advantages:

1 The vane blade is in the undisturbed wind speed and is therefore not hindered by turbulence of the rotor wake.
2 The eccentricity between rotor shaft and tower axis is adequately high (e = 0.087 D). Therefore, the moment which turns the head out of the wind is mainly determined by the thrust on the rotor. Other unfavourable forces like the side force on the rotor, the so called self-orientating moment and the head bearing friction have only a minor effect.
3 As the vane arm is a part of the head, it makes the moment of inertia of the head around the tower axis very large. This results in slow rotation of the head. This reduces the gyroscopic moment in the rotor blades and the generator shaft.
4 At high wind speeds only small changes in the angle between the rotor axis and the wind direction are necessary to come to a new balance of moments.
5 Simple and cheap door hinges can be used for the hinges of the vane blade.

Checking of the head geometry

The head geometry is checked for very low wind speeds. It is assumed that the vane blade is hanging vertical and that the rotor is about perpendicular to the wind. The moment equation around the tower axis for this condition is given by formula 49 or formula 50 of KD 223 (ref. 2). Formula 50 of KD 223 is copied as formula 1.

$$C_n = \pi R^2 * C_t * e / \{h * w * (R_v + i_1)\} \quad (-) \qquad (1)$$

C_n is the normal coefficient for a square plate, R is the rotor radius and R = 0.52 m, C_t is the thrust coefficient of the rotor and C_t = 0.75, h is the height of the vane blade and h = 0.25 m, w is the width of the vane blade and w = 0.25 m, R_v is the distance in between the front edge of the vane blade and the tower centre measured in the direction of the hinge axis and R_v = 0.615 m (measured in the composite drawing), i_1 is the distance in between F_v and the front edge of the vane blade. The ratio i_1 / w as a function of the angle of attack α is given in figure 7 of KD 223. α = 30° if the rotor is perpendicular to the wind. For α = 30°, it can be read that i_1 / w = 0.37. w = 0.25, so i_1 = 0.37 * 0.25 = 0.093 m.

Substitution of these values in formula 1 gives that C_n = 1.296. In figure 6 of KD 223 it can be seen that α = 28° for C_n =1.296. α = 28° corresponds to a yaw angle δ = -2°, so at very low wind speeds, the yaw angle is slightly negative. At low wind speeds the yaw angle will be a little larger, so about 0° and this means that the geometry of the head and the vane blade is correct for the chosen rotor radius, the eccentricity and vane blade and vane arm dimensions.

4 Manufacture of the parts

4.1 General

The information necessary to manufacture the separate parts is given on the drawings given in the appendix. The standard parts are indicated with N. A list of standard parts is given on drawing 1301-00. The description for connecting material like bolts and nuts is in accordance with the description, code number and DIN standard of the Fabory catalogue. In this manual, only parts are described of which it is thought that it is necessary to give additional information.

4.2 Rotor (drawing 1301-01, 1302-01 and 1303-01)

The blade (01) is made from a half hard aluminium strip size 1.5 * 500 * 125 mm. Normally I advice not to use aluminium for rotor blades because aluminium is sensible to fatigue. But as the dynamo has a threaded shaft of only 9 mm diameter, it is important that the gyroscopic moment is as small as possible and therefore aluminium is chosen. 32 blades can be made out of a standard sheet of 1 * 2 m, 50 blades can be made out of a standard sheet of 1.25 * 2.5 m and 72 blades can be made out of a standard sheet of 1.5 * 3 m without waste material. Normally a standard sheet is some mm longer than the nominal value so the tolerance of the width of 125 mm of the last strip should be checked. All three blade strips must be identical!

First the hole spacing is made in the blade root. The hole spacing must be made very accurate to prevent rotor imbalance. One can make a drawing on the computer scale 1 : 1 of the blade root and glue this drawing to the blade root and then centre the holes from the drawing. It is possible to drill three blades together. Next the radius R = 32 mm is made at the blade root using a fret saw or drilling many small holes and using a file. Next the radius R = 5 mm is made on all four corners. The whole outline is rounded with R = 0.3 mm.

Next the 7.14 % camber is made over a length of 400 mm by cambering the blade with R = 220 mm. This can be done using the blade press given on drawing 1302-01. The radius of the pressing block item 03 is only 110 mm because 1.5 mm half hard aluminium bends back a lot in the elastic region. The frame is made of two 400 mm long square beams made of steel bar size 25 * 25 mm. The two beams are connected to each other by two 180 mm long feet, also made of steel bar size 25 * 25 mm. The beams are bevelled at the inside under an angle of 33°. Five 80 mm wide pressing blocks, made of hard wood size 80 * 60 mm, are pressed down by ten inner hexagon bolts M10. The outer 400 mm of the aluminium blade strip is placed under the five pressing blocks and all ten bolts are screwed inwards evenly.

After cambering, the blade has to be twisted 12° right hand in between cross section A and cross section E. Tools to do this are given at drawing 1303-01. Two identical torsion levers item 01 and torsion strips item 02 are used. One torsion lever is clamped in a vice with the hollow side upwards. The blade is clamped in between item 01 and item 02 by means of two screws item 02 N such that the free blade length is 390 mm. The other set of tools is clamped around the blade tip. The blade is twisted about 14° right hand and is then twisted back until the correct angle of 12° is gained. The correct angle can be verified by the 12° jig item 05. As the torsion tools have a thickness of 10 mm, the blade is twisted effectively over a length of 380 mm in stead of 400 mm but this is no problem.

Next the blade is twisted 21° in between cross section E and the flat inner side of the blade which has a length of 30 mm. The outer set of torsion tools is removed. Two flat strips item 07 are slightly clamped around the blade root by two screws 01N. These strips are clamped in a vice such that the blade points upwards. The blade is twisted by turning the first set of torsion tools about 23° left hand and is then twisted back until the correct angle is gained. The correct angle can be verified by the 21° jig item 04. One has to be alert that the blade is only twisted and not bent frontwards or backwards. This can be checked by placing a water-level on the torsion lever.

4.3 Generator (drawing 1301-01)

The generator (01N) is made of a Shimano Nexus hub dynamo type DH-2R40 or another type with similar flange dimensions. The dynamo was ordered at the Dutch bicycle shop ‘t Fietshokje from Amsterdam website: www.fietshokje.nl. It was a special offer with a price of only € 15. However, the costs for delivery are about € 12. I have ordered two dynamos and then the total price for one dynamo is about € 21. The dynamo is supplied without nuts but one needs one nut per dynamo. I have bought one stainless steel nut (02N) for each dynamo in a local bicycle shop and one nut costs € 2. One must be alert to get a special nut M9 * 1 mm for a Nexus hub dynamo because there are nuts on the market with the same pitch but with a thread diameter which is only 0.2 mm larger and these nuts should not be used!

The back dynamo flange is the side were the electricity cable is connected. This side is normally positioned at the right side of the bicycle to realise the correct direction of rotation. The front dynamo flange is the other flange and this flange is modified by making nine 4 mm holes under an angle of 40° from the original 2.6 mm spoke holes. The back flange should be supported by a piece of large diameter pipe with parallel sides during drilling.

4.4 Vane arm assembly (drawing 1301-02)

In contradiction to the head of all other VIRYA-windmills, the head of the VIRYA-1.04 (03) is designed such that it needs no welding. The construction of the pin (03/02) is therefore different. The stainless steel pipe (03/01) is shifted into a hole in the pin (03/02) and then soldered with tin/lead 50/50. The pipe has a length of 1 m. The 21.7 mm hole in the head pin (for the head pipe) can be made on a milling machine. This hole shouldn’t be drilled because this will be not accurate enough. One has to be alert that the bead inside the pipe makes an angle of about 45° with the axis of the pin to prevent cracking of the pipe during pressing of the flat ends. After soldering, the 6 mm central hole in the pin has to be extended in the pipe. This should be done before pressing the pipe ends to be able to remove the drilling curls.

Next the back end of the pipe is bent 15° starting at 275 mm from the end using a pipe bender. The front end of the pipe is flattened vertically over 35 mm and bent 45° along the flat part. The back side is flattened horizontally. Flattening can best be done using a hydraulic press but a strong 125 mm wide vice and some hammering will also work. A 9 mm hole is drilled in the front part for connection of the generator shaft. Six 4.5 mm holes are drilled in the back part for connection of the vane hinges. One has to check if the hole pattern fits with the applied hinges. If one uses hinges size 50 * 50 mm in stead of 50 * 39 mm, one has to modify the hole spacing such that the hinge axis lies at the same place.

4.5 Tower pipe (drawing 1301-03)

The stainless steel tower pipe (06) has a length of 1 m, so just the same as the length of the head pipe. The top bearing seats have to be made accurately on a lath. Four clamps (04) and four threaded rods M6 (05) are used for connection of the tower pipe to a square wooden pole with sides of 80 mm. Two clamping blocks can be made together and should be marked to keep them together.

5 Mounting and installation

The torque level of the generator is too low to stop the rotor by making short-circuit in the winding like it can be done for all other VIRYA-windmills which have generators made of asynchronous motors. This means that the rotor of the VIRYA-1.04 will always turn except at very low wind speeds. So installation of the VIRYA-1.04 windmill should only be done at very low wind speeds! The VIRYA-1.04 has a very low total mass (less than 5 kg) so it is possible to install the complete windmill without special lifting tools. Only a ladder is needed.

The vane blade (02) is connected to the head pipe by means of two hinges (03N) in the workshop. The head bearings are pressed in the tower pipe in the workshop. Tools to do this are given on drawing 1303-01. Item 06 is for the lower bearing and item 05 is for the upper bearing. The rotor blades (01) are mounted to the generator (01N) in the workshop. Mounting of the generator to the vane arm assembly (03) and of the vane arm assembly to the tower pipe (06) is done at the site where the windmill is placed.

The 1 m long tower pipe is too short to mount it against a solid structure like the wall of a shed. It is assumed that a 3 m long wooden pole size 80 * 80 mm is mounted to the wall by two bolts M12 at a pitch of at least 300 mm. The top of this pole should be bevelled 30° and painted with epoxy to prevent entrance of water. The drawing of the pole is not given. Four 6 mm holes are drilled in the pole at a vertical hole spacing of 200 mm and a horizontal hole spacing of 30 mm. One must use the washers (05N) to prevent deformation of the wood and an extra nut M6 (04) in between the clamp and the front washer.
Next only the tower pipe is connected to the wooden pole using the four clamps (04) and the four threaded rods (05). The tower pipe should be vertical within 1°.
Next the generator + rotor assembly is connected to the head by one special Nexus nut.
Next the electricity cable (2 * 1 mm^2, not specified) is pushed upwards to the central hole in the head pin and connected to the generator by the plastic cover supplied to the hub dynamo.
Next the bottom part of the electricity cable (10N) is guided through the top of the tower pipe.
Next the assembly of rotor, generator and head is lifted by one hand and placed on the tower pipe. One should be alert that the cable is guided further downwards and that is isn’t clamped during this action.
Next the electricity cable is connected to a minimum 1.5 A, minimum 50 V, 1-phase bridge rectifier (not specified). The plus and minus of this rectifier are connected to the plus and minus of a 12 V lead-acid battery which must have a capacity of about 30 Ah. As the maximum current is only about 0.43 A, no voltage controller will be needed. But the water level in the battery should be checked regularly, especial at places with high wind speeds.

It is expected that the VIRYA-1.04 windmill will need only little maintenance. It is advised to lubricate the vane hinges with some oil if they start creaking. The clearance of the dynamo bearings should be checked regularly. If there is too much clearance, the front cone can be turned slightly inwards.

The front bearing may be sensible to the entrance of water as it has only a labyrinth seal. This entrance of water can be prevented if a plastic cap with an inside diameter of 36 mm is placed over the front side of the shaft. This plastic cap can be glued to the black teethed collar at the front side of the dynamo. The plastic cap isn’t given on the drawings.

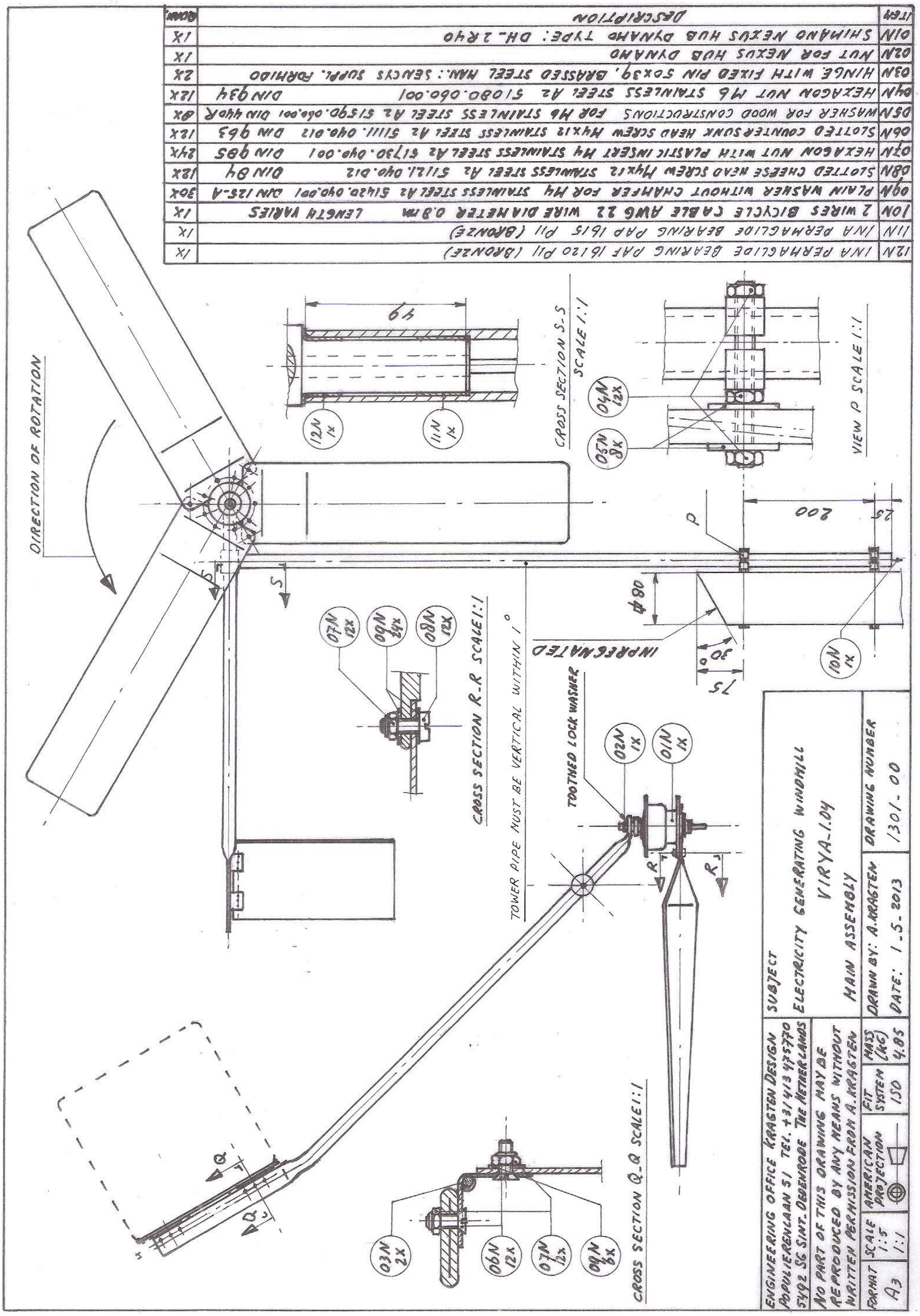
6 References

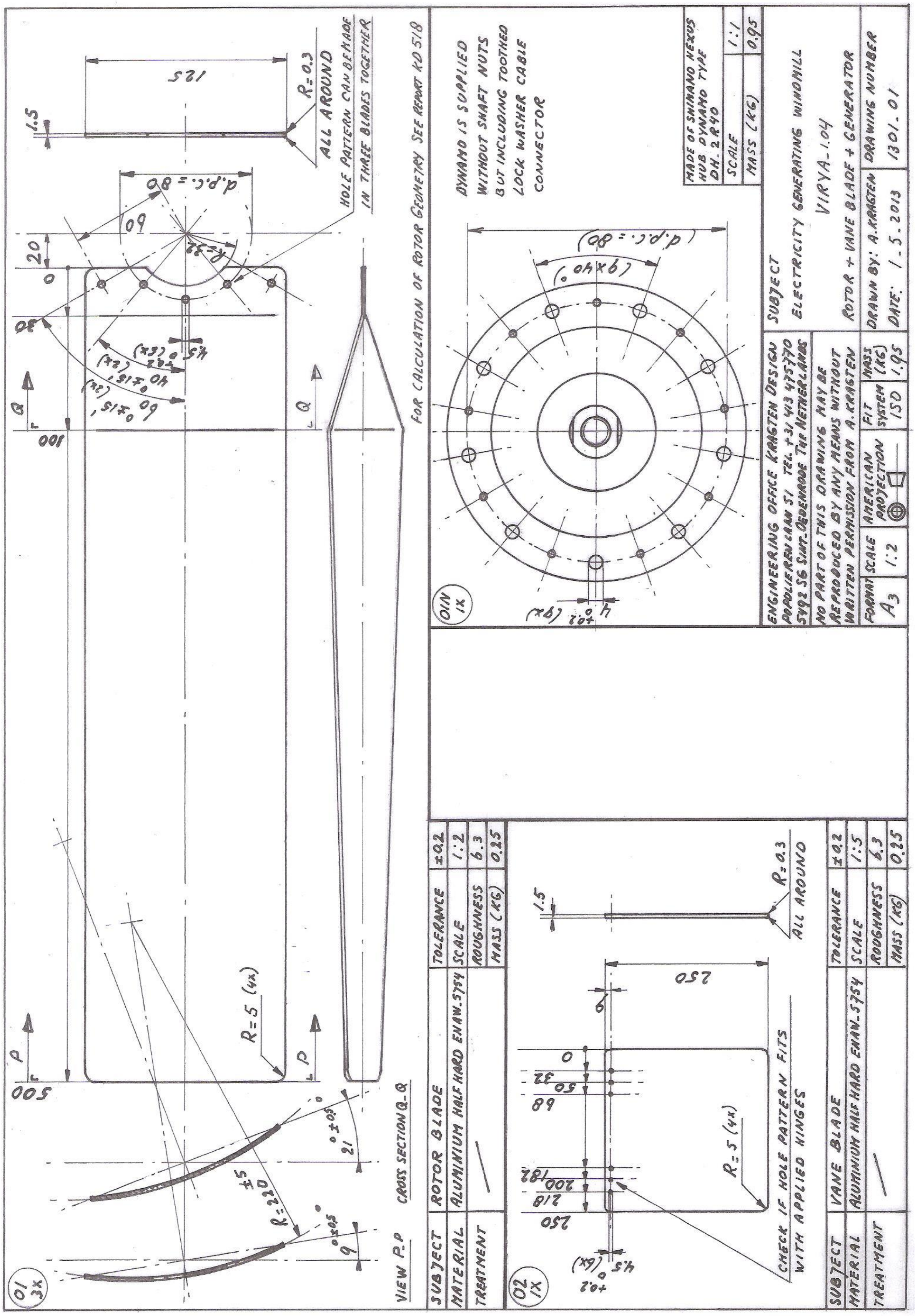
1 Kragten A. Calculations executed for the 3-bladed rotor of the VIRYA-1.04 windmill (λ_d = 3.5, 7.14 % cambered, aluminium blades) meant to be coupled to a Nexus hub dynamo, January 2013, free public report KD 518, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

2 Kragten A. Method to check the estimated δ-V curve of the hinged side vane safety system and checking of the δ-V curve of the VIRYA-3.3D windmill (7.14 % cambered steel blades), February 2005, public report KD 223, nett price € 30, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

3 Kragten A. Safety systems for small wind turbines which turn the rotor out of the wind at high wind speeds, February 2012, free public report KD 485, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

7 Appendix: Drawings of VIRYA-1.04 + blade press + torsion tools

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NO PART OF THIS DRAWING MAY BE REPRODUCED BY ANY MEANS WITHOUT WRITTEN PERMISSION FROM A. KRAGTEN
SUBJECT
ELECTRICITY GENERATING WINDMILL
VIRYA-1.04
ROTOR + VANE BLADE + GENERATOR
DRAWN BY: A. KRAGTEN
DATE: 1.5.2013
DRAWING NUMBER
1301.01
FORMAT A3
SCALE 1:2
AMERICAN PROJECTION
FIT SYSTEM ISO
MASS (KG) 1.95
MADE OF SHIMANO NEXUS HUB DYNAMO TYPE DH-2R40
DYNAMO IS SUPPLIED WITHOUT SHAFT NUTS BUT INCLUDING TOOTHED LOCK WASHER CABLE CONNECTOR
FOR CALCULATION OF ROTOR GEOMETRY SEE REPORT KD 518
HOLE PATTERN CAN BE MADE IN THREE BLADES TOGETHER
R=0.3 ALL AROUND
R=5 (4x)
VIEW P-P
CROSS SECTION Q-Q
SUBJECT ROTOR BLADE
MATERIAL ALUMINIUM HALF HARD EN AW-5754
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS (KG) 0.25
CHECK IF HOLE PATTERN FITS WITH APPLIED HINGES
SUBJECT VANE BLADE
MATERIAL ALUMINIUM HALF HARD EN AW-5754
TOLERANCE ±0.2
SCALE 1:5
ROUGHNESS 6.3
MASS (KG) 0.25