Provisional manual of rotor and generator of

electricity generating windmill

VIRYA-2.2

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Table of contents

1 Introduction

In this manual the rotor and the generator of 2-bladed VIRYA-2.2, electricity generating windmill, are described. This windmill is provided with an 8-pole, 3-phase axial flux generator and is meant for 12 V or 24 V battery charging after star rectification of the winding. The design calculations of the generator and the rotor are given in report KD 607 (ref. 1). The drawings of the rotor and the generator of the VIRYA-2.2 windmill are numbered 1602-01, 1602-02 and 1602-03. These drawings are made on A3 format and are reduced to A4 format. The scanned reduced drawings are incorporated in chapter 7 of this manual.

The VIRYA-2.2 is meant to be used with a head which is derived from the head of the VIRYA-2.2S windmill given on drawing 9904-03/A. The generator bracket has to be modified such that it is in parallel to the rotor plane. The vane blade should be made out of 2 mm aluminium sheet in stead of out of 1 mm stainless steel sheet to realise a rated wind speed of 9 m/s in stead of 11 m/s. The VIRYA-2.2 can also be used in combination with the free standing lattice tower of the VIRYA-2.2S given on drawing 9904-04. The VIRYA-2.2 blades can be cambered by an hydraulic blade press which can be derived from the blade press of the VIRYA-3.8 and VIRYA-4.1 given on drawing 0508-01 as this blade press is meant for the same blade width of 200 mm. However, the VIRYA-2.2 blade press can be made much shorter. A blade can be twisted by tools similar to the tools as given on drawing 0508-02

The VIRYA-2.2 can be used with a 13.8 V or 27.6 V battery charge controller and dump load. The battery charge controller is described in a separate manual (ref. 2) for the VIRYA-1.66. The dump load has drawing number 1104-01. However, one has to use a cooling plate with dimensions 400 * 400 mm and add a fourth transistor to make the dump load strong enough for the higher maximum power of the VIRYA-2.2. This documentation belongs to VIRYA-windmills for which a licence is required and so this documentation isn't available for free. These five drawings and one manual are available for a reduced licence fee of € 500 excluding 21 % VAT, if relevant.

Those who are not able to pay the licence fee for the documents as mentioned above, still can build a VIRYA-2.2 wind turbine if they design their own head, tower and battery charge controller and if they develop their own tools to camber and twist the blades. The windmill should never be used without a proper safety system which limits the rotational speed and thrust at high wind speeds. Information about safety systems is given in report KD 485 (ref. 3). The hinged side vane safety system as used in all VIRYA-windmills is described in detail in report KD 223 (ref. 4). A simple way to design the hinged side vane safety system, is to scale up the head geometry of the VIRYA-1.36 windmill by about a factor 1.62. Use a 1.5 m long 1 ¼ " vane pipe and a 2 m long 1 ½ " tower pipe and a 25 mm head pin. The VIRYA-1.36 head has drawing number 1407-05 (see manual of the VIRYA-1.36 ref. 5). In the manual of the VIRYA-1.04 (ref. 6) there is an example of tools to camber and twist the blades. As the VIRYA-2.2 has 2.5 mm thick and 200 mm wide stainless steel blades cambered over 800 mm and as the VIRYA-1.04 has 1.5 mm thick and 125 mm wide aluminium blades cambered over 400 mm, the blade press must be 425 mm longer and 75 mm wider. The radius of the pressing blocks is found by try and error. One has to take a small strip of 2.5 mm stainless steel and bend it around disks of different diameter until the correct bending radius is found. One has to make an 8.5° jig to verify the correct blade angles.

Drawing 1602-01 is the sub assembly of rotor + generator and also contains a list with standard parts (indicated with --N) which are required to connect all parts together.
Drawing 1602-02 gives a detailed drawing of the rotor blade (01), the bearing housing (02), the bearing filler bush (03), the long distance bush (04) and the short distance bush (05).
Drawing 1602-03 gives a detailed drawing of the armature sheet (06), the stator sheet (07) and the core + coil (08).

The maximum power of the VIRYA-2.2 windmill is expected to be about 200 W at a maximum charging voltage of 14 V. So the maximum charging current is about 14.3 A. This current is too high to use the windmill without a battery charge controller and dump load which limits the charging voltage at about 13.8 V for a full 12 V battery and at about 27.6 V for a full 24 V battery. Over charging a full battery results in splitting up of water in Hydrogen and Oxygen which is dangerous in combination with open fire and it results in strong reduction of the life time.

The VIRYA-2.2 is designed by:

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With the drawings given at the appendix, it is possible to manufacture a prototype of the generator but I won't do this as I don't have the required machines. Probably I can measure the prototype on a test rig which was recently developed for a small Chinese axial flux generator. However, this requires a special ring to connect the generator to the flange of the test rig. The test rig is described in report KD 595 (ref. 7). If the generator works well, two blades have to be made too. It might be possible to test the assembly of rotor and generator on the modified head of the VIRYA-2.2 windmill which is placed on the 12 m tower of the VIRYA-4.2. The total tower height then becomes about 14 m which guarantees an acceptable wind regime.

Although the VIRYA-2.2 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.

2 Specification

Diameter	D = 2.2 m
Number of blades	B = 2
Design tip speed ratio	$\lambda_d = 4.5$
Gear ratio	i = 1
Rotor eccentricity	e = 0.18 m
Tower height for tower pipe only	H = 2 m
Mass rotor + generator	m = 15.5 kg
Starting wind speed	$V_{start} = 2.6$ m/s
Survival wind speed	$V_{surv} = 30$ m/s
Cut in wind speed (if started)	$V_{cut\ in} = 3$ m/s
Rated wind speed	$V_{rated} = 9$ m/s
Nominal voltage	12 V or 24 V DC
Power at rated wind speed	P = 200 W

3 The safety system

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. 4). 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 N cos θ around the tower axis is in balance with the moment of the thrust on the rotor F_t (see KD 223 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 m/s up to 9 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 turned about 75° out of the wind. The rotor speed will be about constant for wind speeds between 9 m/s and 30 m/s. These are the values for a 2 mm aluminium vane blade.

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 = 0.082 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.

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. The description for connecting material like bolts and nuts and electronics is in accordance with the description, code number and DIN standard of the Fabory catalogue and the Farnell 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 1602-02)

A rotor blade (01) is made from a stainless steel strip size 2.5 * 1000 * 100 mm. 10 blades can be made out of a standard sheet of 1 * 2 m without waste material. Normally a standard sheet is some mm longer than the nominal value so the tolerance of the width of 200 mm of the last strip should be checked. The two blade strips of one rotor must be identical to prevent blade imbalance.

First the hole spacing is made in the blade root. The hole spacing must be made very accurate to prevent rotor imbalance. It might be possible to drill two blades together. Accurate drilling requires a milling machine or hardened drilling jigs. Next the radius R = 5 mm is made on all four corners. The whole outline is rounded with R = 0.7 mm.

Next the 7.14 % camber is made over a length of 800 mm by cambering the blade with R = 352 mm. This can be done by an hydraulic blade press which is derived from the hydraulic blade press of the VIRYA-3.8 and the VIRYA-4.1. It might also be possible to use a modified blade press of the VIRYA-1.04 given in the VIRYA-1.04 manual at drawing 1302-01. The radius of the pressing block has to be found by try and error by using a 2.5 mm strip of the used stainless steel and bend it around cylinders of different diameter until the correct radius is found. It will be much smaller than 352 mm because the blade bends back in the elastic region.

After cambering, the blade has to be twisted. The blade is not twisted over the outer 800 mm. The blade is twisted 8.5° in between cross section E and the inner side of the blade where it is connected to the generator. Similar tools to do this are given for the VIRYA-1.04 at drawing 1303-01. 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 as set of torsion tools about 10° right hand and is then twisted back until the correct angle of 8.5° is gained. The correct angle can be verified by the jig item 04 of drawing 1303-01 which must have an angle of 8.5° for the VIRYA-2.2. One has to be alert that the blade is only twisted and not bent forwards or backwards. This can be checked by placing a water-level on the torsion lever.

4.3 Coil + core (drawing 1602-03)

At the date of writing this provisional manual, the generator has not yet been built and measured. So the required wire thickness and the number of turns per coil are not yet known but I expect that the required wire thickness is about 1 mm. The procedure how to determine the winding is given in chapter 9 of KD 607 (ref. 1).

The VIRYA-2.2 winding has six separate coils. The wire ends A and B are guided through holes in the stator sheet. The winding direction of all coils is the same. The 14 mm chamber for the connecting screw M8 * 25 must point to the front side for all cores at mounting of the cores against the stator sheet.

The coil cores are made of polyacetal (or POM) and have a central hole with a diameter of 8 mm. So the winding thorn must have a shaft with a diameter of 8 mm at the cores. It is assumed that the left side of winding thorn has a diameter of 20 mm and that this side is clamped in a driving unit which can be the head stock of a lath for the prototype. The 8 mm shaft has M8 thread at the end. Two aluminium disks with a central hole of 8 mm, an outer diameter of 88 mm and a thickness of 6 mm are used to prevent that the flanges of the core bend to the outside due to the wire pressure .

First an aluminium disk is shifted over the shaft. Next a core is placed with the 14 mm chamber to the left. Next the second aluminium disk is placed. This second aluminium disk must have a 2 mm hole at a radius of 26 mm such that the beginning wire can be feed in through this hole. Everything is clamped together by a nut M8.

One needs a driving unit with variable speed to drive the winding thorn. The number of revolutions has to be counted by a counter. If the number of turns per coil and the wire thickness are determined correctly, it means that the outside coil diameter is just 88 mm for the required number of turns per coil and the required thickness of the enamelled copper wire. The last layer is covered by some epoxy lacquer to prevent that the last layer unwinds when the winding thorn is disconnected. One may also wrap an extra piece of tape around the coil to prevent unwinding. Hardening of the epoxy lacquer will take some time, so one needs some extra winding thorns to continue production for the other coils.

4.4 Armature sheet (drawing 1602-03)

Eight neodymium magnets size ϕ 45 * 15 mm have to be glued to the back side of the armature sheet in such a way that four north poles and four south poles are created. For correct positioning it is advised to make a 4 mm thick Teflon sheet with the same geometry as the armature sheet and with a hole pattern such that it can be bolted to the armature sheet. The Teflon sheet should have eight holes round 45 mm at the correct pitch circle and the correct position.

Eight magnets are piled together with isolation sheets in between them. Arrows are placed at the sides of each magnet in the same direction. First four magnets are glued by epoxy to the armature sheet and the arrows on these first four magnets are pointing upwards. Next four magnets are glued in between the first four ones and the arrows on these second four magnets are pointing downwards.

4.5 Modification of the VIRYA-2.2S vane arm assembly (drawing 9904-03/A)

The VIRYA-2.2S has a stainless steel vane blade size 1 * 500 * 500 mm. The rated wind speed for this vane blade is about 11 m/s. The rated wind speed for the VIRYA-2.2 is chosen lower to prevent too high temperatures of the winding and the stator sheet. It is chosen to take a 2 mm aluminium vane blade size 2 * 500 * 500 mm. The rated wind speed for this vane blade is about 9 m/s. The vane blade stop item 06 must also be modified for a 2 mm vane blade. The angle 10° becomes 15° and the angle 18° becomes 23°.

The VIRYA-2.2S makes use of a generator which is made from an asynchronous motor frame size 80. The head frame is provided with a generator bracket which is in parallel to the rotor axis. For the VIRYA-2.2, the generator bracket must be in parallel to the rotor plane so it must be rotated 90°. The vane pipe item 01/01 is the same but it must be rotated 90° before welding it to the head pin item 01/02. The strip item 01/03 should not be rotated! The bracket is made out of stainless steel strip size 70 * 6 mm. The length must be chosen such that the eccentricity e in between the rotor axis and the tower axis is 180 mm.

5 Mounting and installation

The maximum torque level of the generator might be 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-2.2 will always turn except at very low wind speeds. So installation of the VIRYA-2.2 windmill should only be done at very low wind speeds! The VIRYA-2.2 is rather heavy so the head can only be mounted when the tower is laid down. One needs a winch and an auxiliary tower to erect the tower.

The vane blade (05) is connected to the head pipe by means of two hinges (04N) in the workshop. The head bearings (05N) and (06N) are pressed in the head bearing housing in the workshop using a tool given left of the cross section over the head bearing on drawing 9904-03/A. The head pin of the vane arm assembly is mounted in the head bearing housing in the workshop using the outer retaining ring (03N).

The mounting sequence of the generator and the rotor is as follows:

1 Clean the shaft and the inside of the bearings with acetone or alcohol.
2 A bearing filler bush item 03 is glued to the shaft by epoxy glue.
3 The back bearing item 11 is pressed on the bearing filler bush.
4 The 60 mm long distance bush is shifted over the shaft.
5 A second bearing filler bush item 03 is glued to the shaft by epoxy glue.
6 The front bearing item 11 is pressed on the bearing filler bush. The bearings have to be pressed together during hardening of the glue. This can be done by the short distance bush and the nut M16. The second bush shouldn't be glued to the shaft.
7 The nut and the short distance bush are removed after hardening of the glue.
8 The assembly of shaft and bearings is pushed in the bearing housing.
9 The oil seal item 12 N is pressed in the stator sheet.
10 The 3-phase rectifier item 13 N is mounted to the back side of the stator sheet.
11 The six coils are mounted against the stator sheet. The twelve cable ends are guided through the twelve holes in the stator sheet. Each cable end is covered by a piece of glass sleeving item 14 N.
12 If the generator is used for 12 V battery charging all wire ends B are connected to each other and are forming the star point. The wire ends A of the same phase are connected to an AC point of the rectifier item 13 N (see for wire diagram figure 1 of KD 607). If the generator is used for 24 V battery charging one needs an extra 12 pole connector with which it is possible to connect the two coils of one phase in series.
13 The stator is bolted to the bearing housing using four bolts M8 * 20.
14 The 37 mm long short distance bush is pushed over the shaft.
15 The eight magnets are glued to the back side of the rectangular armature sheet such that four north and four south poles are created. To prevent corrosion, the assembly of sheet and magnets has to be painted by epoxy lacquer.
16 The assembly of the armature sheet and the magnets and is shifted over the shaft and locked with the central M16 nut. A 14 mm spanner can be put in the screw head.
17 The two blades are bolted to the front side of the armature sheet using eight stainless steel bolts M8 * 30 which are shortened to 20 mm, eight stainless steel self locking nuts M8 and eight stainless steel washers. Don't use hexagon screws M8 * 20 because the centrifugal force in the blades should no be transferred to the armature sheet by thread.
18 The rotor is balanced on a frictionless shaft at a windless place.
19 The lattice tower is mounted to the foundation and the tower is supported by a gin such that the tower top is about 1 m above the ground.
20 The tower pipe is clamped in the top of the lattice tower.
21 The vane arm assembly with the head bearings mounted is shifted in the tower pipe
22 The assembly of generator and rotor is bolted to the generator bracket of the head frame using four bolts M12 * 25 mm.
23 The electricity cable 2 * 1.5 mm^2 (not specified) is pushed through the central hole in the head pin. The upper part of the cable is connected to the 3-phase rectifier of the generator by two crimp terminals (15N).
24 The bottom part of the electricity cable is guided through centre of the lattice tower and connected to a 2-pole connector. From this connecter one can use a 2 pole wire with massive copper wires which is connected to the battery charge controller and the batteries.
25 If all connections are made, the tower can be erected.

It is expected that the VIRYA-2.2 windmill will need only little maintenance as is it almost made completely out of stainless steel. It is advised to lubricate the vane hinges with some oil if they start creaking. The water level in the battery should be checked regularly, especial at places with high wind speeds.

6 References

1 Kragten A. Development of an 8-pole, 3-phase axial flux generator for the VIRYA-2.2 windmill using 8 circular neodymium magnets size ϕ 45 * 15 mm. Design report of the rotor (λ_d = 4.5, B = 2, stainless steel blades), February 2016, free public report KD 607, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

2 Kragten A. Manual of a 13.8 V, 165 W battery charge controller for the VIRYA-1.65 + VIRYA-1.66 + VIRYA-1.75B2 windmills, January 2016, 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.

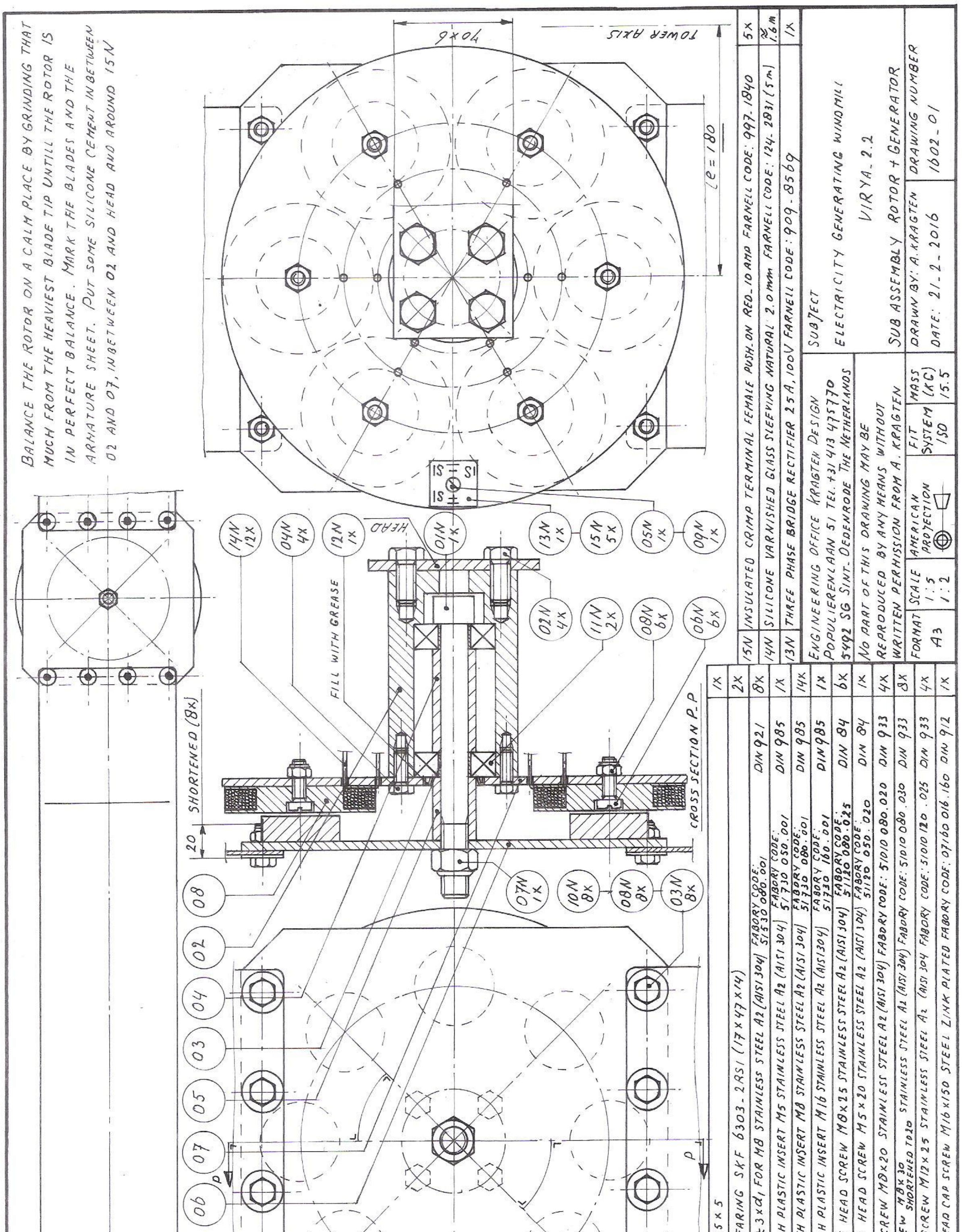
4 Kragten A. Method to check the estimated δ-V curve of the hinged side vane safety system and checking of the δ-V curve of the VIRYA-3.3D windmill (7.14 % cambered steel blades), February 2005, free public report KD 223, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The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

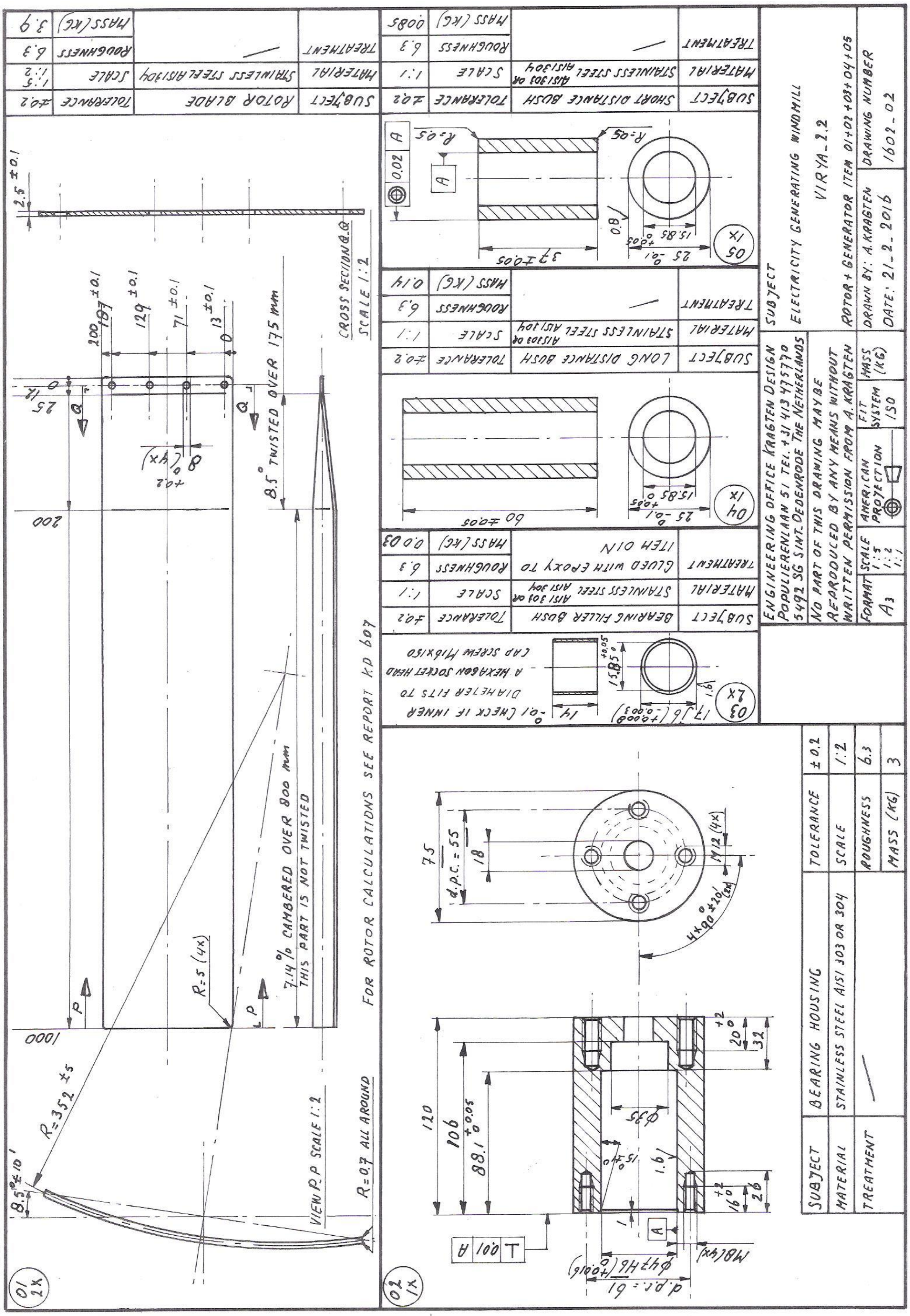
5 Kragten A. Manual of electricity generating windmill VIRYA-1.36, November 2015, free manual (see menu KD-reports), engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

6 Kragten A. Manual of electricity generating windmill VIRYA-1.04, March 2014, free manual (see menu KD-reports), engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

7 Kragten A. Measurements performed on a Chinese axial flux generator of Hefei Top Grand model TGET165-0.15kW-500R for a 12 V battery load, September 2015, free public report KD 595, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

7 Appendix: Drawings of VIRYA-2.2

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5492 SG SINT-OEDENRODE THE NETHERLANDS
NO PART OF THIS DRAWING MAY BE
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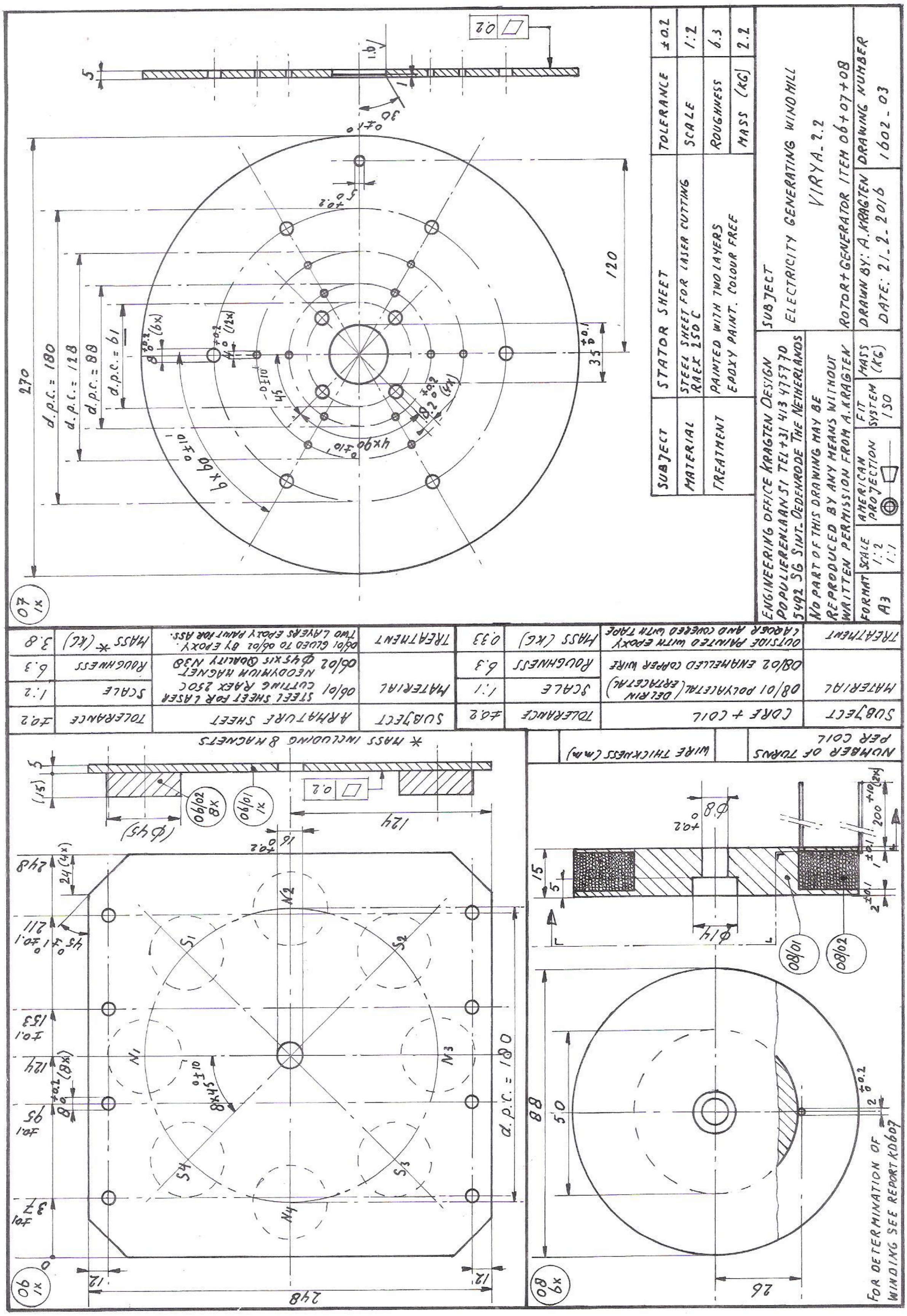
WRITTEN PERMISSION FROM A. KRAGTEN
SUBJECT
ELECTRICITY GENERATING WINDMILL
VIRYA_2.2
ROTOR + GENERATOR ITEM 01+02+03+04+05
DRAWN BY: A. KRAGTEN
DATE: 21-2-2016
DRAWING NUMBER
1602_02
FORMAT A3
SCALE 1:5 1:2 1:1
AMERICAN PROJECTION
FIT SYSTEM ISO
MASS (KG)
SUBJECT ROTOR BLADE
MATERIAL STAINLESS STEEL AISI 304
SUBJECT SHORT DISTANCE BUSH
SUBJECT LONG DISTANCE BUSH
SUBJECT BEARING FILLER BUSH
GLUED WITH EPOXY TO ITEM 01N
SUBJECT BEARING HOUSING
MATERIAL STAINLESS STEEL AISI 303 OR 304
TOLERANCE ± 0.2
ROUGHNESS 6.3
CROSS SECTION Q-Q SCALE 1:2
8.5° TWISTED OVER 175 mm
7.14 % CAMBERED OVER 800 mm
THIS PART IS NOT TWISTED
FOR ROTOR CALCULATIONS SEE REPORT KD 607
VIEW P-P SCALE 1:2
R=0.7 ALL AROUND
R=352 ±5
A HEXAGON SOCKET HEAD CAP SCREW M16x150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SUBJECT
ELECTRICITY GENERATING WINDMILL
VIRYA-2.2
ROTOR+GENERATOR ITEM 06+07+08
DRAWN BY: A. KRAGTEN
DATE: 21-2-2016
DRAWING NUMBER
1602-03
FORMAT A3
SCALE 1:2 1:1
AMERICAN PROJECTION
FIT SYSTEM ISO
MASS (KG)
SUBJECT STATOR SHEET
MATERIAL STEEL SHEET FOR LASER CUTTING RAEX 250 C
TREATMENT PAINTED WITH TWO LAYERS EPOXY PAINT. COLOUR FREE
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS (KG) 2.2
SUBJECT ARMATURE SHEET
MATERIAL 06/01 STEEL SHEET FOR LASER CUTTING RAEX 250C
06/02 NEODYMIUM MAGNET Ø45x15 QUALITY N38
TREATMENT 06/01 GLUED TO 06/02 BY EPOXY. TWO LAYERS EPOXY PAINT FOR ASS.
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS * (KG) 3.8
* MASS INCLUDING 8 MAGNETS
SUBJECT CORE + COIL
MATERIAL 08/01 POLYACETAL (DELRIN ERTACETAL)
08/02 ENAMELLED COPPER WIRE
TREATMENT OUTSIDE PAINTED WITH EPOXY
TOLERANCE ±0.2
SCALE 1:1
ROUGHNESS 6.3
MASS (KG) 0.33
NUMBER OF TURNS PER COIL
WIRE THICKNESS (mm)
FOR DETERMINATION OF WINDING SEE REPORT KD607