Provisional manual of rotor and generator of

electricity generating windmill

VIRYA-1.66

It is allowed to copy this manual for private use. Anyone is allowed to build the VIRYA-1.66 windmill described in this manual and in report KD 596 but the windmill is not yet tested. No responsibility is accepted by Kragten Design for possible failures.

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January 2016

Table of contents

1 Introduction

In this manual the rotor and the generator of 3-bladed VIRYA-1.66, electricity generating windmill, are described. This windmill is provided with a 12-pole, 3-phase axial flux generator and is meant for 12 V battery charging after star rectification of the winding. The design calculations of the generator and the rotor are given in report KD 596 (ref. 1). The drawings of the rotor and the generator of the VIRYA-1.66 windmill are numbered 1601-01, 1601-02 and 1601-03. 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-1.66 is meant to be used with a head which is derived from the head of the VIRYA-1.8 windmill given on drawing 9903-03. The VIRYA-1.66 can also be used in combination with the free standing tower of the VIRYA-1.8 given on drawing 9903-04. The VIRYA-1.66 blades can be cambered by the hydraulic blade press of the VIRYA-1.8 and VIRYA-2.2S given on drawing 9905-01/A and twisted by tools given on drawing 9905-02. The VIRYA-1.66 can be used with a 13.8 V battery charge controller and dump load. The battery charge controller is described in a separate manual (ref. 2). The dump load has drawing number 1104-01. 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-1.66 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 1.22. Use a 1.2 m long 1" vane pipe and a 2 m long 1 ¼" tower pipe and a 20 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 a VIRYA-1.66 blade has 2 mm thick stainless steel blades cambered over 625 mm and as the VIRYA-1.04 has 1.5 mm thick aluminium blades cambered over 400 mm, the blade press must be 225 mm longer. The radius of the pressing blocks must be about 140 mm. One has to make a 6° jig and a 14° jig to verify the correct twist and blade angles.

Drawing 1601-01 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 1601-02 gives a detailed drawing of the rotor blade (01), the bearing housing (02), the long distance bush (03) and the short distance bush (04).
Drawing 1601-03 gives a detailed drawing of the armature sheet (05), the stator sheet (06) and the core + coil (07).

The maximum power of the VIRYA-1.66 windmill is expected to be about 130 W at a maximum charging voltage of 14 V. So the maximum charging current is about 9.3 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 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-1.66 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. If someone wants to manufacture a prototype, I can supply the twelve magnets. 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, I can manufacture three stainless steel blades and the assembly of rotor and generator can be tested on the modified head of the VIRYA-1.8 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-1.66 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 = 1.66 m
Number of blades	B = 3
Design tip speed ratio	λ_d = 4.5
Gear ratio	i = 1
Rotor eccentricity	e = 0.15 m
Tower height for tower pipe only	H = 2 m
Mass rotor + generator	m = 9.1 kg
Starting wind speed	V_{start} = 2.3 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 DC
Power at rated wind speed	P = 130 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 5 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 = 0.09 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 1601-02)

A rotor blade (01) is made from a stainless steel strip size 2 * 750 * 125 mm. 48 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. The three 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 three blades together. Accurate drilling requires a milling machine or hardened drilling jigs. Next the radius R = 2 mm is made on all four corners. The whole outline is rounded with R = 0.5 mm.

Next the 7.14 % camber is made over a length of 625 mm by cambering the blade with R = 220 mm. This can be done by the hydraulic blade press developed for the VIRYA-1.8 and the VIRYA-2.2S. 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 mm strip of the used stainless steel and bend it around cylinders of different diameter until the correct radius is found. It will be about 140 mm which is much smaller than 220 mm because the blade bends back in the elastic region.

After cambering, the blade has to be twisted 6° right hand in between cross section A and cross section F. Tools to do this are given for the VIRYA-1.04 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 615 mm. The other set of tools is clamped around the blade tip. The blade is twisted about 8° right hand and is then twisted back until the correct angle of 6° is gained. The correct angle can be verified by item 05 of drawing 1303-01 which must have an angle of 6° for the VIRYA-1.66. As the torsion tools have a thickness of 10 mm, the blade is twisted effectively over a length of 605 mm in stead of 625 mm but this is no problem.

Next the blade is twisted 14° in between cross section F and the flat inner side of the blade which has a length of 24 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 16° left hand and is then twisted back until the correct angle of 14° is gained. The correct angle can be verified by the jig item 04 of drawing 1303-01 which must have an angle of 14° for the VIRYA-1.66. 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 1601-07)

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 596 (ref. 1). Tests have been performed to determine the wire thickness and the number of turns per coil.

The three coils of one phase have to be made together to eliminate soldering points. The winding direction of all coils is the same. The 9 mm chamber for the connecting screw M5 * 16 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 5 mm. So the winding thorn must have a shaft with a diameter of 5 mm at the cores. It is assumed that the left side of winding thorn has a diameter of 15 mm and that this side is clamped in a driving unit which can be the head stock of a lath for the prototype. The 5 mm shaft has M5 thread at the end. Four brass disks with a central hole of 5 mm, an outer diameter of 56 mm and a thickness of 4 mm are also used.

First a brass disk is shifted over the shaft. Next the left core is placed with the 9 mm chamber to the left. Next the second brass disk is placed. Next the middle core is placed with the 9 mm chamber to the left. Next the third brass disk is placed. Next the right core is placed with the 9 mm chamber to the left. Next the last brass disk is placed. Everything is clamped together by a nut M5. If the 9 mm chambers are pointing in the same direction on the winding thorn, the winding direction will be the same if the cores are mounted to the stator sheet.

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 58 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. Hardening of the epoxy lacquer will take some time, so one needs at least two extra winding thorns to continue production for the coils of the other two phases.

4.4 Armature sheet (drawing 1601-03)

Twelve neodymium magnets size 25.4 * 25.4 * 12.7 mm have to be glued to the back side of the armature sheet in such a way that six north poles and six 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 twelve square holes size 25.5 * 25.5 at the correct pitch circle and the correct position.

Twelve magnets are piled together with isolation sheets in between them. Arrows are placed at all four free sides of each magnet in the same direction. First six magnets are glued by epoxy to the armature sheet and the arrows on these first four magnets are pointing upwards. Next six 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-1.8 vane arm assembly (drawing 9903-03)

The VIRYA-1.8 has a stainless steel vane blade size 1 * 416 * 416 mm. The rated wind speed for this vane blade is about 11 m/s. The rated wind speed for the VIRYA-1.66 is chosen lower to prevent too high temperatures of the winding and the stator sheet. The VIRYA-1.66 has a smaller rotor diameter and the vane blade can therefore be smaller. It is chosen to take an aluminium vane blade size 2 * 375 * 375 mm, so 32 vane blades can be made from a standard sheet size 1.5 * 3 m. The rated wind speed for this vane blade is about 9 m/s. The hole pattern for the hinges must be made symmetrical with respect to the vane blade width.

The VIRYA-1.8 makes use of a generator which is made from an asynchronous motor frame size 71. The head frame is provided with a generator bracket which is in parallel to the rotor axis. For the VIRYA-1.66, the generator bracket must be in parallel to the rotor plane so it must be rotated 90°. The bracket is made out of stainless steel strip size 60 * 4 mm. The length must be chosen such that the eccentricity in between the rotor axis and the tower axis is 150 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-1.66 will always turn except at very low wind speeds. So installation of the VIRYA-1.66 windmill should only be done at very low wind speeds! The VIRYA-1.66 has a low total mass (about 22 kg) so it is possible to install the complete windmill without special lifting tools. Only a ladder is needed.

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 9903-03. 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 given in chapter 5 of KD 596. The rotor blades (01) can be mounted to the generator in the workshop. Don’t forget to balance the rotor. Mounting of the assembly of rotor + generator to the vane arm assembly and of the vane arm assembly to the tower pipe is done at the site where the windmill is placed.

The 2 m long tower pipe is probably too short to mount it against a solid structure like the wall of a shed. It is assumed that a 3 m long hard wooden pole size 85 * 85 mm is mounted to the wall by two bolts M12 at a pitch of at about 600 mm. The top of this pole should be bevelled 30° and painted with epoxy to prevent entrance of water. The drawing of the pole isn’t given. Four 10 mm holes are drilled in the pole at a vertical hole spacing of 300 mm and a horizontal hole spacing of 60 mm. One must use heavy washers for M10 to prevent deformation of the wood and an extra nut M10 in between the clamp and the pole.

Next only the tower pipe is connected to the wooden pole using the four clamps (03) and four stainless steel threaded rods M10 (not specified). The tower pipe should be vertical within 1°.

Next the generator + rotor assembly is connected to the generator bracket of the head assembly by four bolts M8 * 16 (02N) .

Next the electricity cable 2 * 1.5 mm^2 (not specified) is pushed upwards to the central hole in the head pin and connected to the 3-phase rectifier of the generator by two crimp terminals (15N).

Next the bottom part of the electricity cable is guided through the top of the tower pipe. Next the assembly of rotor, generator and head is lifted 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 60 Ah battery (not specified) such that the plus of the wire corresponds to the plus of the battery.

It is expected that the VIRYA-1.66 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. Ideas about a 12-pole axial flux generator for the VIRYA-1.66 windmill using 12 neodymium magnets size 25.4 * 25.4 * 12.7 mm. Design report of the rotor (λ_d = 4.5, B = 3, stainless steel blades), October 2015, reviewed January 2016, free public report KD 596, 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.

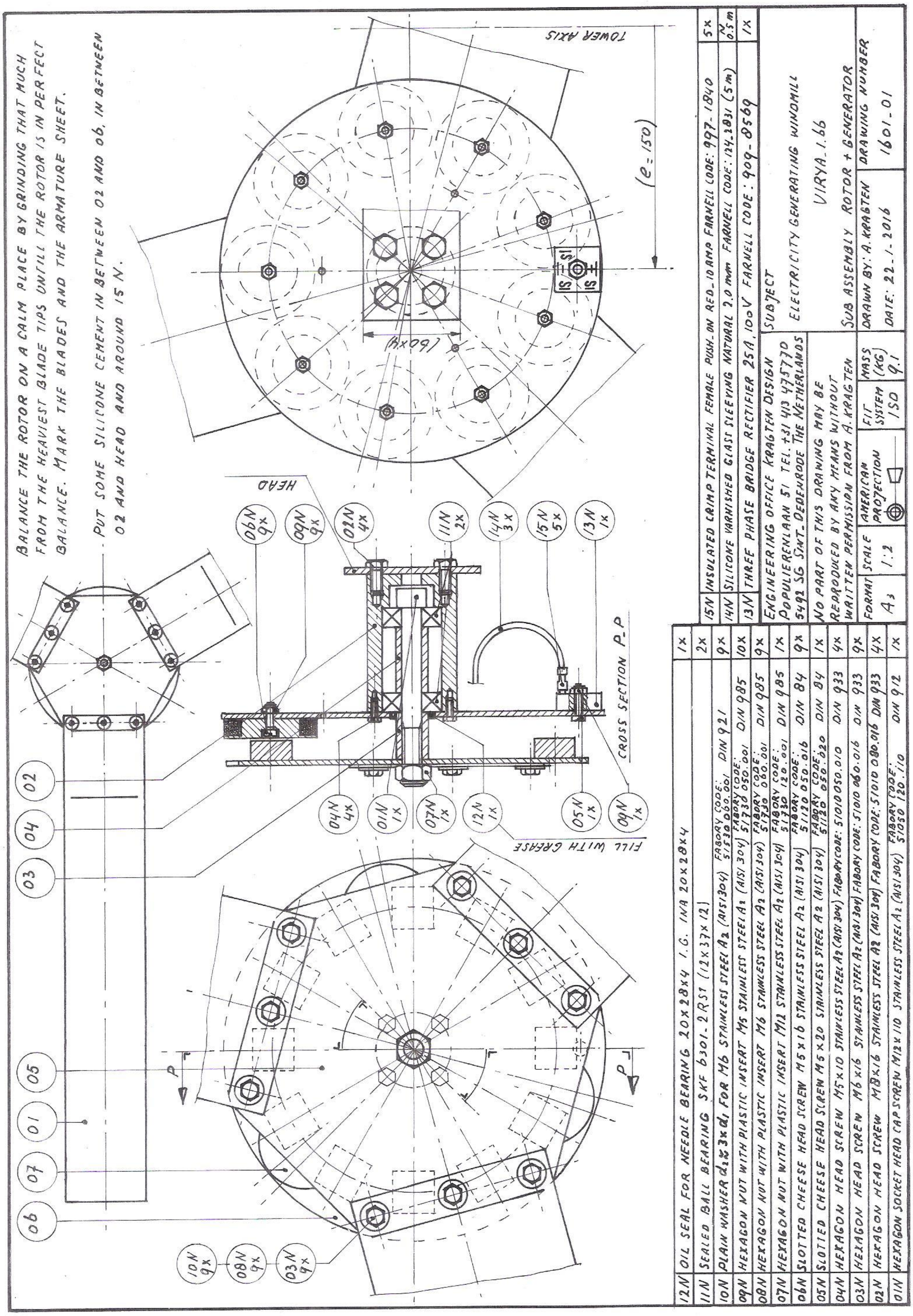
4 Kragten A. Method to check the estimated δ-V curve of the hinged side vane safety system and checking of the δ-V curve of the VIRYA-3.3D windmill (7.14 % cambered steel blades), February 2005, free public report KD 223, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The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

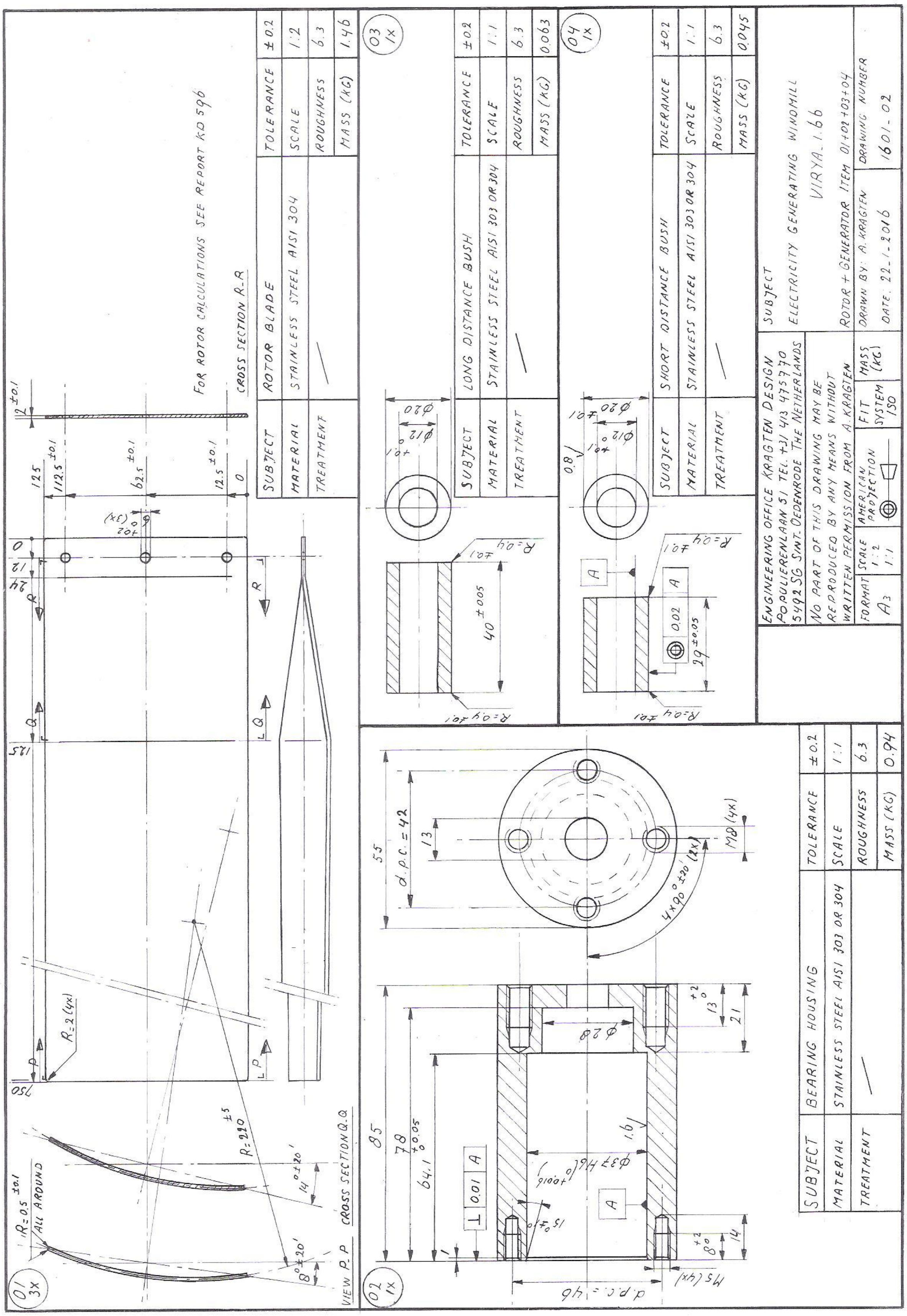
5 Kragten A. Manual of electricity generating windmill VIRYA-1.36, November 2015, free manual (see menu KD-reports), engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

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-1.66




FOR ROTOR CALCULATIONS SEE REPORT KD 596
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VIEW P-P
CROSS SECTION Q-Q
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MATERIAL STAINLESS STEEL AISI 304
TREATMENT
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS (KG) 1.46
SUBJECT LONG DISTANCE BUSH
MATERIAL STAINLESS STEEL AISI 303 OR 304
TOLERANCE ±0.2
SCALE 1:1
ROUGHNESS 6.3
MASS (KG) 0.063
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TOLERANCE ±0.2
SCALE 1:1
ROUGHNESS 6.3
MASS (KG) 0.94
ENGINEERING OFFICE KRAGTEN DESIGN
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5492 SG SINT-OEDENRODE THE NETHERLANDS
NO PART OF THIS DRAWING MAY BE REPRODUCED BY ANY MEANS WITHOUT WRITTEN PERMISSION FROM A. KRAGTEN
SUBJECT
ELECTRICITY GENERATING WINDMILL
VIRYA-1.66
ROTOR + GENERATOR ITEM 01+02+03+04
DRAWN BY: A. KRAGTEN
DATE: 22-1-2016
DRAWING NUMBER 1601-02
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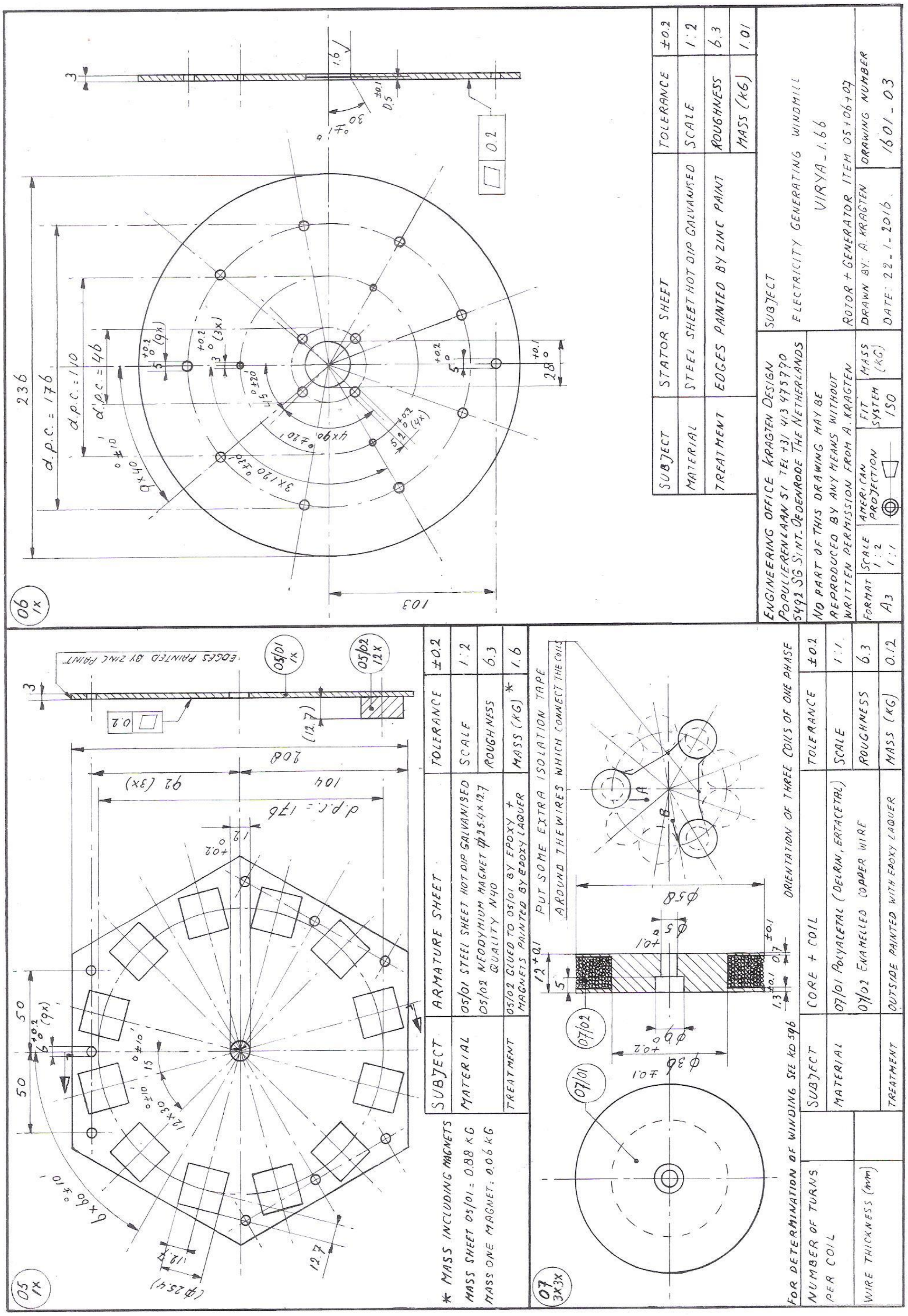
FIT SYSTEM ISO


06
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EDGES PAINTED BY ZINC PAINT
SUBJECT
MATERIAL
TREATMENT
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS (KG) 1.01
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ELECTRICITY GENERATING WINDMILL
VIRYA_1.66
ROTOR + GENERATOR ITEM 05+06+07
DRAWN BY: A. KRAGTEN
DATE: 22-1-2016
DRAWING NUMBER
1601_03
FORMAT A3
SCALE 1:2 1:1
AMERICAN PROJECTION
FIT SYSTEM ISO
MASS (KG)
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1x
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05/02 NEODYMIUM MAGNET Ø25.4x12.7 QUALITY N40
05/02 GLUED TO 05/01 BY EPOXY + MAGNETS PAINTED BY EPOXY LAQUER
TOLERANCE ±0.2
SCALE 1:2
ROUGHNESS 6.3
MASS (KG) * 1.6
* MASS INCLUDING MAGNETS
MASS SHEET 05/01 = 0.88 KG
MASS ONE MAGNET: 0.06 KG
EDGES PAINTED BY ZINC PAINT
07
3x3x
CORE + COIL
07/01 POLYACETAL (DELRIN, ERTACETAL)
07/02 ENAMELLED COPPER WIRE
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SCALE 1:1
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MASS (KG) 0.12
PUT SOME EXTRA ISOLATION TAPE
AROUND THE WIRES WHICH CONNECT THE COILS
ORIENTATION OF THREE COILS OF ONE PHASE
FOR DETERMINATION OF WINDING SEE KD 596
NUMBER OF TURNS PER COIL
WIRE THICKNESS (mm)