Ideas about the use of the 3-bladed VIRYA-3B3 rotor (λ_d = 6.5) in combination with the axial flux PM-generator of Hefei Top Grand type TGET320-1KW-350R for 48 V battery charging

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 The VIRYA-3B3 rotor hasn't been tested in combination with the specified PM-generator. The VIRYA-3B3 rotor should only be used if the windmill has a proper safety system!

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1 Introduction

The VIRYA-3B3 windmill has a 3-bladed rotor with wooden blades which are connected to each other by means of a hub plate which is laser cut from 5 mm stainless steel or galvanised steel sheet. The VIRYA-3B3 rotor has a design tip speed ratio of 6.5. The rotor calculations of the VIRYA-3B3 are given in report KD 484 (ref. 1). The VIRYA-3B3 is provided with the hinged side vane safety system and the rated wind speed is about 9.5 m/s. This safety system is described in general in chapter 3.2 of report KD 485 (ref. 2).

The VIRYA-3B3 is standard provided with a radial flux PM-generator made from an asynchronous motor. This generator type is described in chapter 4 of report KD 341 (ref. 3). The generator has been measured for different load conditions and the measurements are given in report KD 78 (ref. 4). The generator has a 3-phase winding and the current is rectified for battery charging. Rectification of a 3-phase current is explained in report KD 340 (ref. 5). The generator has good characteristics but manufacture of the permanent magnet armature requires strong skills. So it is investigated if a standard PM-generator can be used.

A generator of Chinese manufacture has been chosen. A 1 kW axial flux generator is found which is supplied by different Chinese suppliers like Hefei Top Grand, Xinda Green Energy, Hiestmotor and Qiangsheng Magnets. I have chosen Hefei Top Grand, website: www.china-topgrand.com because they gave the clearest answers on my questions. I have bought and tested a smaller generator type TGET165-0.15kW-500R at this company and they keep their promises. Measurements for this generator are given in report KD 595 (ref. 6).

For the VIRYA-3B3, I have chosen the largest generator which can be used for 48 V battery charging. This appears to be the generator with type TGET320-1KW-350R (320 refers to about the housing diameter, 350 refers to the nominal rotational speed). The generator is of the type "Outer Rotor" which means that the whole generator housing is rotating around the shaft. The rated voltage at n = 350 rpm is specified as 56VDC. 56 V is the maximum charging voltage for a 48 V battery. This generator has a 3-phase winding connected in star and the three cables are coming out of the hollow generator shaft. A large 3-phase rectifier (not included) must be used to get a DC current for 48 V battery charging. A copy of the supplier's specification of this generator is given in appendix 2

2 Characteristics of the VIRYA-3B3 rotor

The 3-bladed rotor of the VIRYA-3B3 windmill has a diameter D = 3 m and a design tip speed ratio λ_d = 6.5. Advantages of a 3-bladed rotor are that the gyroscopic moment in the rotor shaft isn't fluctuating and that a 3-bladed rotor looks nicer than a 2-bladed one.

The rotor has wooden blades with a constant chord and no twist and is provided with a Gö 623 or a Gö 711-12 % airfoil over the whole blade length. The Gö 711-12 % is flat over 97.5 % of the chord and is therefore easier to manufacture. The maximum thickness of both airfoils is 12 % of the chord. The chord is chosen 150 mm, so the maximum thickness is 18 mm. A blade is made out of a plank of good quality hard wood. A photo of the detailed rotor drawing is given in appendix 2 of KD 484 (ref. 1) for use of the rotor in combination with the original generator. However, the axial flux generator of Hefei Top Grand has a much larger outside diameter and the hub plate and the length of the blades have to be modified for use of the VIRYA-3B3 rotor with this generator. A sketch of the modified rotor and hub plate is given in appendix 1.

The P-n curves for certain constant wind speeds and the optimum cubic line are given in figure 4 of KD 484. This figure is copied as figure 1. Figure 4 of KD 484 also gives the measured P_{mech}-n and P_{el}-n curves of the original generator (with a modified 115/200 V winding) for 26 V star. These curves are removed from figure 1 and replaced by the estimated curves of the chosen axial flux generator of Hefei Top Grand. The procedure how these curves are derived from the specification of the supplier is given in chapter 3.

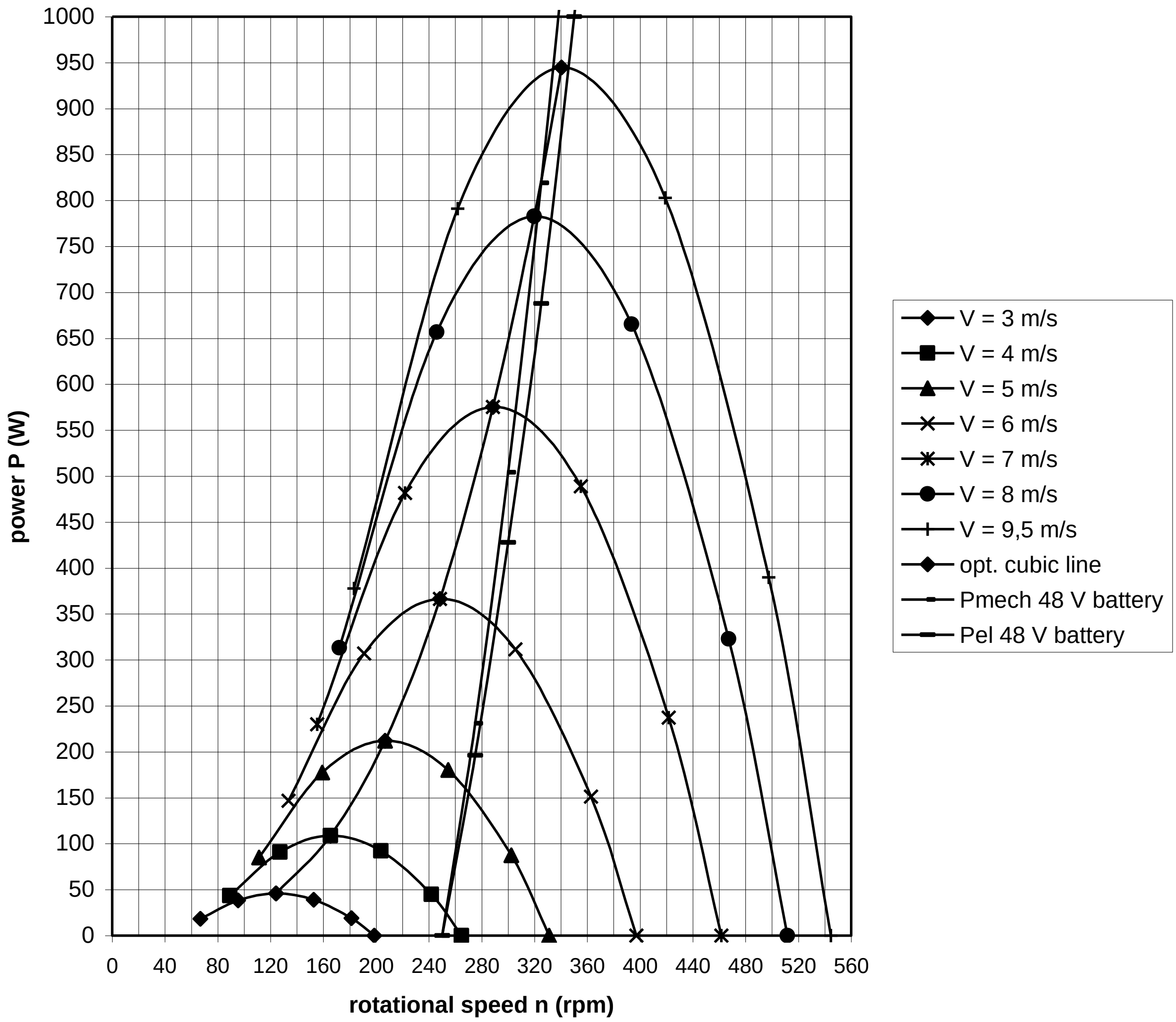

fig. 1 P-n curves of the VIRYA-3B3 rotor for V_{rated} = 9.5 m/s, optimum cubic line, estimated P_{mech}-n and P_{el}-n curves of the generator type TGET320-1KW-350R for 48 V battery charging, rectification in star.

The characteristics of the generator for short-circuit of the winding are not known. The star point can't be short-circuited as it is hidden somewhere in the winding. So one can only short-circuit the three wires coming out of the hollow generator shaft. The generator can only be used as a brake by making short-circuit if the P-n curve for short-circuit is lying left from the P-n curve of the rotor for V = 9.5 m/s. If this isn't the case, the generator winding can burn if the rotor is running for a long time at high rotational speeds! Short-circuit must be made as close as possible to the generator to prevent a voltage drop over the lines. In practice this means that the short-circuit switch must be placed before the rectifier at the tower foot and not at the batteries. The rectifier can also be placed at the tower foot, so there are only two cables from the tower foot to the batteries.

3 Derivation of the P_{mech}-n and P_{el}-n curves for a 48 V battery load

For checking of the matching in between rotor and generator and for the determination of the P_{el}-V curve, measured P_{mech}-n and P_{el}-n curves of the generator for a 48 V battery load are needed. A 48 V battery is charged at an average charging voltage of about 52 V so the P_{mech}-n curve and the P_{el}-n curve should have been measured for this constant voltage. However, Hefei Top Grand supplies only a P_{el}-n curve for a resistance load. The resistance R is chosen such that the electrical power is 1000 W at a rotational speed of 350 rpm and a loaded voltage of 56 VDC. But at lower rotational speeds, the characteristics for a resistance load differ very much from the characteristics for a constant voltage. So the characteristics for a constant voltage have to be estimated to check the matching in between rotor and generator.

An unloaded or open U-n curve isn't given by Hefei Top Grand but it is given on the website of Xinda Green Energy: www.xindaenergy.com. This company supplies this generator for two different voltages 220VAC and 56VDC. The 56VDC curve is rather small and difficult to read. It has very unusual numbers on the U-axis being 0, 12, 25, 49, 62 and 74 V. The open U-n curve is a straight line through the origin and it is read that U = 68 V for n = 350 rpm. So the open voltage is reduced from 68 V up to 56 V if an electrical power of 1000 W is extracted. This is a rather low voltage reduction for this rated power and this might be caused by the high given efficiency of 85 %. An axial flux generator can have a high efficiency because it has no iron in the coils where energy is lost because of eddy currents.

My PM-generator using a motor housing 5RN90L04V has been measured for different load conditions. The measurements are given in report KD 78 (ref. 4). The measurements for a constant resistance show that the P_{mech}-n and P_{el}-n curves are about parabolas if the torque is not close to the maximum torque level which the generator can supply. This is in accordance with the P_{el}-n curve given in the Hefei Top Grand folder which is about a parabola. The P_{mech}-n and P_{el}-n curves of the generator can be derived by the formulas:

$$Q = 30 \, P_{mech} / (\pi * n) \quad \text{(Nm)} \qquad (1)$$

$$P_{mech} = 100 * P_{el} / \eta \quad \text{(W)} \qquad (2)$$

No rated torque is given for the Hefei Top Grand generator. However, it is specified that the efficiency is at least 85 % and I assume that this is true for the rated rotation speed n = 350 rpm and the rated electrical power of P_{el} = 1000 W. Substitution of P_{el} = 1000 W and η = 85 % in formula 2 gives that P_{mech} = 1176 W. Substitution of P_{mech} = 1176 W and n = 350 rpm in formula 1 gives that Q = 32.1 Nm. The Q-n curve starts at the rotational speed for which the open generator voltage is equal to the open battery voltage. It is assumed that the open battery voltage is 48.5 V. An open generator voltage of 48.5 V is generated at a rotational speed of 350 * 48.5 / 68 = 250 rpm.

Next it is assumed that the Q-n curve is a straight line through the calculated points for n = 250 rpm and n = 350 rpm. It has found for measurements of my VIRYA generators that this is about true if the torque is not lying close to the maximum torque which the generator can supply. The torque Q is calculated for rotational speeds of 250, 275, 300, 325, 350 and 375 rpm. The value of P_{mech} is calculated for each rotational speed using formula 2. The value of P_{el} is calculated by assuming a constant efficiency of 85 %. The result of the calculations is given in table 1. The values at 375 rpm may be too high because the calculated torque may lie close to the maximum torque which the generator can supply.

n (rpm)	Q (Nm)	P_{mech} (W)	η (%)	P_{el} (W)
250	0	0	85	0
275	8.025	231	85	196
300	16.05	504	85	428
325	24.075	819	85	688
350	32.1	1176	85	1000
375	40.025	1572	85	1336

table 1 Estimated values for Q, P_{mech} and P_{el} for the axial flux generator of Hefei Top Grand type TGET320-1KW-350R with a 56VDC winding for a 48 V battery load.

The P_{mech}-n and P_{el}-n curves derived from table 1 are also given in figure 1. The point of intersection of the P_{mech}-n curve of the generator with the P-n curve of the rotor for a certain wind speed, gives the working point for that wind speed. The electrical power P_{el} for that wind speed is found by going down vertically from the working point up to the point of intersection with the P_{el}-n curve. The values of P_{el} found this way for all wind speeds, are plotted in the P_{el}-V curve (see figure 2).

The matching of rotor and generator is only good for high wind speeds because only then, the P_{mech}-n curve of the generator is lying close to the optimum cubic line of the rotor. In the P_{el}-V curve it can be seen that the maximum electrical power is 800 W which is rather high for a rotor with a diameter of 3 m and a rated wind speed of 9.5 m/s. The supply of power starts at a wind speed of 3.8 m/s ($V_{cut\ in}$ = 3.8 m/s). This is rather high and only acceptable low for regions with moderate wind speeds.

The starting wind speed depends on the sticking torque of the generator. It is specified that this torque is smaller than 0.3 Nm. However, this is only true if no oil seal is mounted at the generator shaft. The generator is supplied without an oil seal and I expect that the housing has a chamber in which an oil seal can be mounted. If the generator is used for a horizontal axis windmill like we do, an oil seal is needed to prevent entrance of water. It is assumed that even with an oil seal, the starting wind speed is lower than 3 m/s, so there is no hysteresis in the P_{el}-V curve.

The P_{el}-V curve given in figure 2 is based on estimated P_{mech}-n and P_{el}-n curves of the generator for a 48 V battery load. These curves are therefore not accurate. For accurate curves, it is required to buy a generator and measure it on an accurate test rig for a big real 48 V battery as load or for a 52 V battery simulator as load, like it is done for the VIRYA generators on the test rig of the University of Technology Eindhoven. If this is done properly, one will find that the efficiency for a battery load isn't constant but that it has a peak at a rather low rotational speed and that it decreases at higher rotational speeds (see figure 10 KD 78, ref. 4).

The batteries have to be protected by over charging by a voltage controller and dump load which limits the maximum charging voltage up to about 56 V. The battery voltage can be transformed into a 1-phase grid by a 230 V, 50 Hz inverter. This inverter will also prevent that the batteries are discharged if the voltage is lower than about 44 V. It might be possible to connect the VIRYA-3B3 directly to a 3-phase grid by a grid connected 3-phase inverter. This inverter has to be adjusted such that the maximum input DC voltage is 56 V. The input voltage at low wind speeds can be lower than the minimum battery charging voltage of about 48.5 V and therefore the matching at low wind speeds will be better than for a battery load resulting in a lower cut-in wind speed and in a higher output at low wind

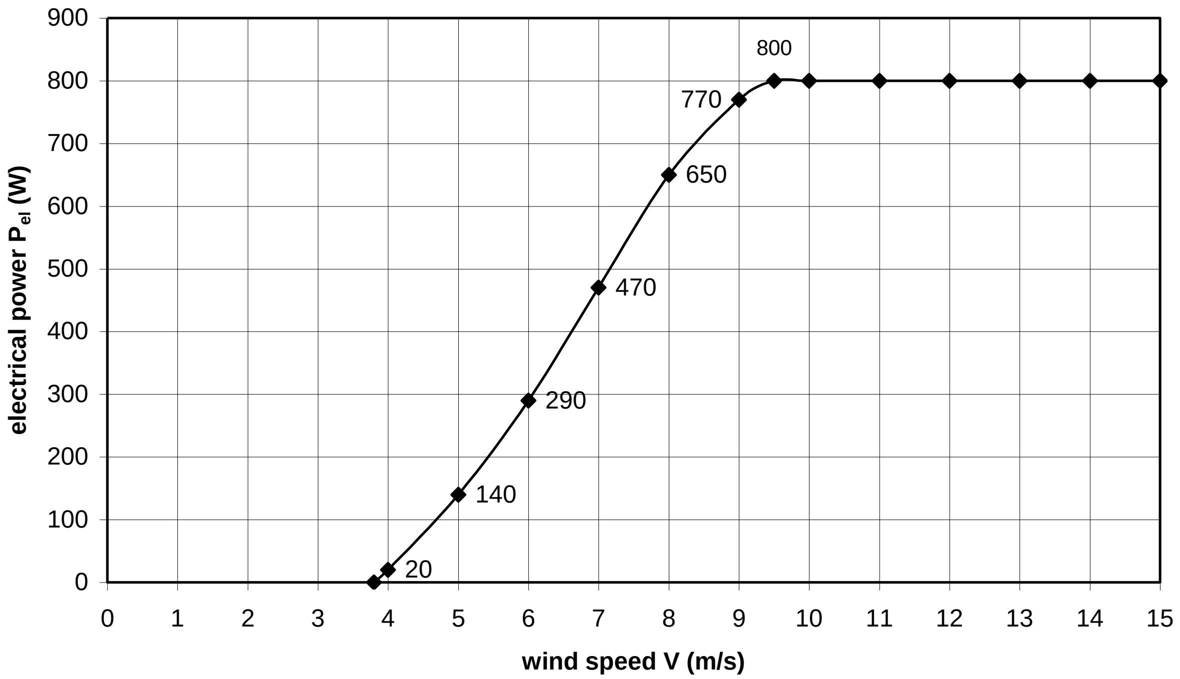

fig. 2 Estimated P_{el}-V curve of the VIRYA-3B3 windmill with a generator of Hefei Top Grand type TGET320-1KW-350R for 48 V battery charging

4 Modifications of the VIRYA-3B3 head

Detailed drawings of the VIRYA-3B3 rotor, generator, head and tower have already been made in 2012 when Kragten Design was still a commercial company. All these drawings are made on A1 format. At that time, a licence of the VIRYA-3B3 could be bought and this licence included a complete set of drawings and a manual. As I have stopped my commercial activities at 1-1-2018, these drawings are now no longer available.

But even if they would available, modification of the original head frame is necessary because the axial flux generator is connected differently to the head frame as the original generator. So one has to design his own head frame and tower. The geometry of the head frame is given for the VIRYA-4.2 in report KD 213 (ref. 7). So one must scale down this geometry with about a factor 3 / 4.2 = 0.714. The eccentricity e of the head frame of the original VIRYA-3B3 is 0.26 m.

The main goal of writing this report KD 705 is not to present a new VIRYA windmill but to show the method as given in chapter 3 of how the specification of the supplier of a PM-generator can be transformed into the wanted P_{mech}-n and P_{el}-n curves. To check the matching, one needs P-n curves of the rotor and the VIRYA-3B3 rotor was taken as an example. As the P_{mech}-n and P_{el}-n curves are rather steep, it is shown that the matching is only good for high wind speeds.

5 References

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3 Kragten A. Development of the permanent magnet (PM) generators of the VIRYA windmills, May 2007, reviewed May 2017, free public report KD 341, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

4 Kragten A. Measurements performed on a generator with housing 5RN90L04V and a 4-pole armature equipped with neodymium magnets, March 2001, reviewed March 2015, free public report KD 78, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

5 Kragten A. Rectification of 3-phase VIRYA windmill generators, May 2007, reviewed October 2014, free public report KD 340, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

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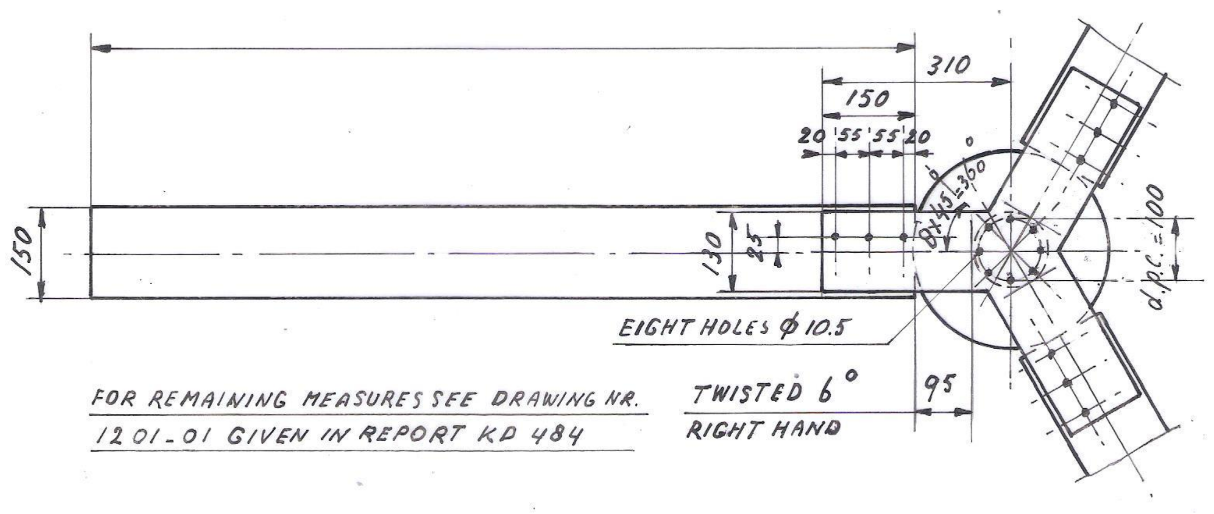
7 Kragten A. Method to check the estimated δ-V curve of the hinged side vane safety system and checking of the δ-V curve of the VIRYA-4.2 windmill, December 2004, free public report KD 213, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

Appendix 1 Sketch VIRYA-3B3 rotor with wooden blades



Appendix 2 Folder Hefei Top Grand TGET320-1KW-350R

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keywords

PRODUCT

- Permanent Magnet Generator
  1. Inner Rotor
  2. Outer Rotor
- Horizontal Wind Turbine
  1. TGWT-S Series
  2. TGWT-M Series
  3. TGWT-L Series
  4. TGWT-G Series
- Vertical Axis Wind Turbine

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PRODUCT DETAIL

1.Model: TGET320-1KW-350R

2. Character

Our disc coreless PMG have advantage in low Rated speed, Low starting wind speed, Small volume, Energy Small, Light weight, Compact structure,High efficiency etc.

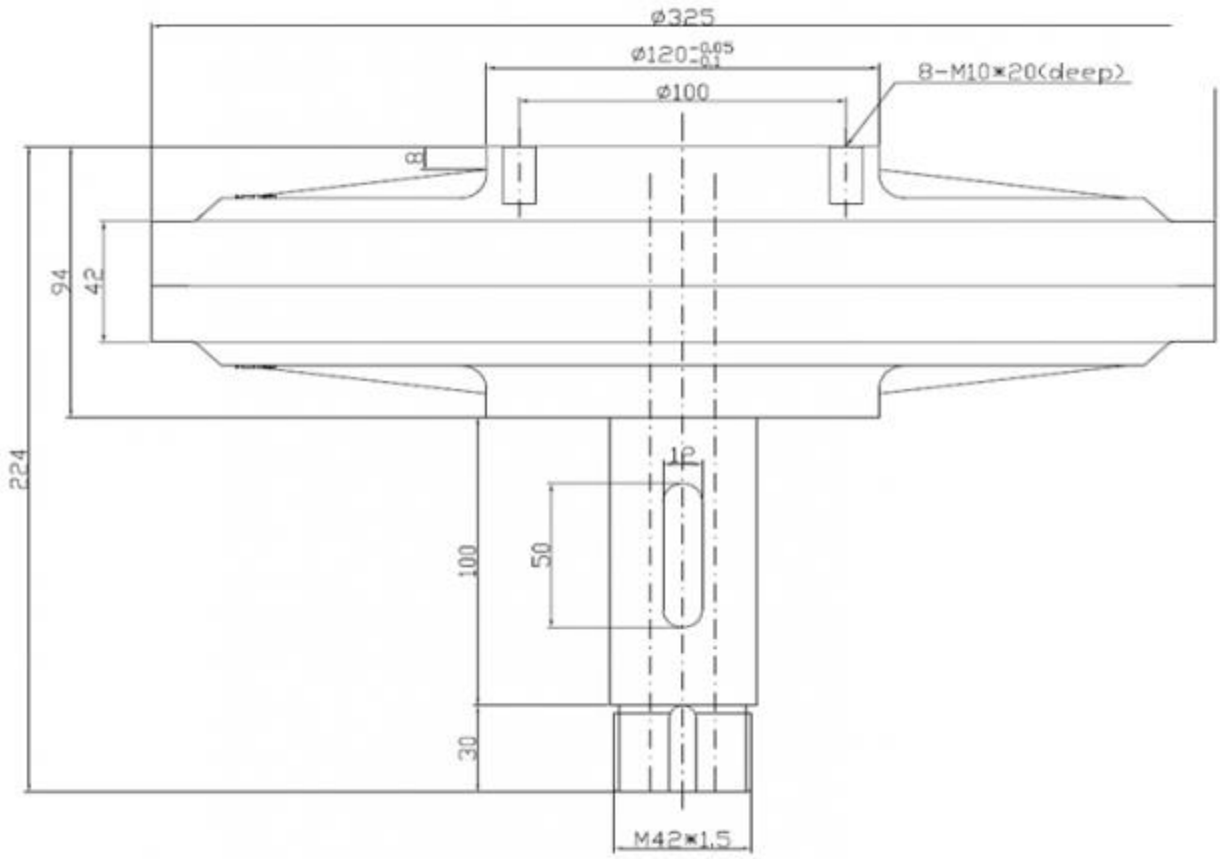
1) Coreless, anhysteresis, slotless, have low starting torque.
2) No iron loss, have high efficiency
3) Adopt unique coreless precision winding technology design precision coil
4) Adopt the rare earth permanent magnet, which is multipole, mean gap, high power density and high output power.
5) Low speed direct driving, no torque fluctuations
6) Compact structure, high ratio of power to volume

7) No iron loss, low calorific value, small temperature rise
8) Simple structure, easy to install
9) The brushless structure, free maintenance

3. Range Of Application

0.5-1 kw wind turbine; gasoline generators; hydroelectric generator

4. Shape Drawing



5. Performance Parameter

NO.	PARAMETER	UNITS	DATA
1	Rated power	KW	1
2	Rated speed	RPM	350
3	Rated voltage	V	56VDC
4	Rated Line Current		12.89A
6	Efficiency		>85%
7	Resistance (Line-Line)		-
8	Winding type		Y
9	Insulation Resistance		100Mohm Min(500V DC)
10	Leakage level		<5 ma
11	Start torque	N/M	<0.3
12	Phase		Three phase
13	Structure		outer rotor
14	Stator		coreless
15	Rotor		Permanent magnet type (outer rotor)
16	Gen. Diameter	mm	325
17	Gen. Length	mm	224
18	Gen. Weight	kg	20
19	Shaft. Diameter	mm	45
20	Housing Material		Aluminum (Alloy)
21	Shaft Material		Steel
22	Gross Weight	KG	25

6. Curve Graph