Calculations executed for the 2-bladed rotor of the VIRYA-2.22 windmill (λ_d = 5, stainless steel blades) using the axial flux PM-generator of Hefei Top Grand model TGET260-0.5KW-350R

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The generator characteristics have been estimated and the VIRYA-2.22 wind turbine has not yet been tested.

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Contains page

1 Introduction

The VIRYA-2.22 windmill is developed for manufacture in western countries as well as in developing countries. The VIRYA-2.22 has a 2-bladed rotor with stainless steel blades. The construction of the rotor is about similar to the construction of the VIRYA-1.25 rotor which has been tested for ten years except that the VIRYA-2.22 has separate blades.

The VIRYA-2.22 is meant for 24 V battery charging and makes use of a Chinese axial flux generator of Hefei Top Grand model TGET260-0.5KW-350R. All other VIRYA windmills also have PM-generators which are described in report KD 341 (ref. 1). Some of them have radial flux generators made from asynchronous motors which have a stator lamination made of iron sheets and therefore they have a certain sticking torque. The chosen PM-generator for the VIRYA-2.22 is of the type axial flux and has an armature which is rotating around the stator. The stator contains no iron and the sticking torque will therefore be rather low. This results in a low starting wind speed even if a rotor with a low starting torque coefficient is used. More information about the generator is given in chapter 6. Certain PM-generators of the older VIRYA windmills have been measured on an accurate test rig of the University of Technology Eindhoven. The most complete measuring report is report KD 78 (ref. 2) in which a PM-generator has been measured for different load conditions.

The windmill is provided with the so called hinged side vane safety system. The head is identical to the head of the VIRYA-2.2S with a 3-bladed rotor but two special clamps are needed to connect the axial flux generator to the generator bracket. The vane blade is made of 1 mm stainless steel resulting in a rated wind speed of about 10 m/s. The hinged side vane safety system is described in general in chapter 3.2 of public report KD 485 (ref. 3).

2 Description of the rotor of the VIRYA-2.22 windmill

The rotor of the VIRYA-2.22 windmill has a diameter D = 2.22 m, a number of blades B = 2 and a design tip speed ratio λ_d = 5. Advantages of a 2-bladed rotor are that no welded spoke assembly is required and that the rotor can be balanced and transported easily.

The rotor has stainless steel blades with a constant chord and is provided with a 7.14 % cambered airfoil over the whole length of the blade. A blade is made out of a stainless steel strip with dimensions of 2 * 208 * 830 mm and 18 blades can be made from a standard sheet size 1.25 * 2.5 m. The chord c is a little smaller than the blade width because of the camber and this results in c = 205 mm = 0.205 m.

The two blades are connected to each other by a stainless steel central strip with dimensions 4 * 156 * 625 mm and 32 strips can be made from a standard sheet size 1.25 * 2.5 m. The overlap in between a blade and the central strip is 32.5 mm, resulting in a free blade length of 797.5 mm. This free blade length in combination with a sheet width of 208 mm and a sheet thickness of 2 mm should be short enough to prevent blade flutter at high tip speeds. The chosen dimensions give a rotor diameter of 2 * 830 + 625 – 2 * 32.5 = 2220 mm = 2.22 m.

The central 110 mm, where the central strip is connected to the generator, is flat. The two 32.5 mm long ends, where the strip is connected to the blades, are cambered with the same camber as used for the blades. A part of about 60 mm is used for the transition of camber to flat. So a 220 mm long part outside the flat central part is not cambered but only twisted to give the blade the correct blade angle at the blade root. The central strip is rather flexible and this neutralises most of the vibrations due to the fluctuating gyroscopic moment of a 2-bladed rotor. A blade is connected to the central strip by three bolts M8 and three self locking nuts M8.

The generator has a 110 mm collar at the front side with eight threaded holes M8 at a pitch circle of 90 mm. The central strip is connected to the generator by eight bolts M8 * 25 and some locking liquid. The rotor is balanced by grinding that much from the heaviest blade tip until the rotor is in perfect balance.

3 Calculation of the rotor geometry

The rotor geometry is determined using the method and the formulas as given in report KD 35 (ref. 4). This report (KD 676) has its own formula numbering. Substitution of $\lambda_d = 5$ and R = 1.11 m in formula (5.1) of KD 35 gives:

$$\lambda_{r\,d} = 4.5045 * r \qquad (-) \qquad (1)$$

Formula's (5.2) and (5.3) of KD 35 stay the same so:

$$\beta = \phi - \alpha \qquad (°) \qquad (2)$$

$$\phi = 2/3 \arctan 1 / \lambda_{r\,d} \qquad (°) \qquad (3)$$

Substitution of B = 2 and c = 0.205 m in formula (5.4) of KD 35 gives:

$$C_l = 61.299\ r\ (1 - \cos\phi) \qquad (-) \qquad (4)$$

Substitution of V = 5 m/s and c = 0.205 m in formula (5.5) of KD 35 gives:

$$R_{e\,r} = 0.684 * 10^5 * \sqrt{(\lambda_{r\,d}^2 + 4/9)} \qquad (-) \qquad (5)$$

The blade is calculated for six stations A till F which have a distance of 0.166 m of one to another. Station F corresponds to the blade root. The blade has a constant chord and the calculations therefore correspond with the example as given in chapter 5.4.2 of KD 35. This means that the blade is designed with a low lift coefficient at the tip and with a high lift coefficient at the root. First the theoretical values are determined for C_l, α and β and next β is linearised such that the twist is constant and that the linearised values for the outer part of the blade correspond as good as possible with the theoretical values. The result of the calculations is given in table 1.

The aerodynamic characteristics of 7.14 % cambered airfoil are given in report KD 398 (ref. 5). The Reynolds values for the stations are calculated for a wind speed of 5 m/s because this is a reasonable wind speed for a good wind regime. Those airfoil Reynolds numbers are used which are lying closest to the calculated values.

sta-tion	r (m)	λ_{rd} (-)	ϕ (°)	c (m)	$C_{l\,th}$ (-)	$C_{l\,lin}$ (-)	$R_{e\,r} * 10^{-5}$ V = 5 m/s	$R_e * 10^{-5}$ 7.14 %	α_{th} (°)	α_{lin} (°)	β_{th} (°)	β_{lin} (°)	$C_d/C_{l\,lin}$ (-)
A	1.11	5	7.5	0.205	0.59	0.69	3.45	3.4	-0.9	-0.5	8.4	8.0	0.043
B	0.944	4.252	8.8	0.205	0.68	0.72	2.94	2.5	-0.2	0.0	9.0	8.8	0.040
C	0.778	3.505	10.6	0.205	0.82	0.85	2.44	2.5	0.7	1.0	9.9	9.6	0.034
D	0.612	2.757	13.3	0.205	1.00	0.94	1.94	1.7	3.5	2.9	9.8	10.4	0.042
E	0.446	2.009	17.6	0.205	1.29	1.27	1.45	1.2	6.6	6.4	11.0	11.2	0.049
F	0.280	1.261	25.6	0.205	1.69	1.33	0.98	1.2	-	13.6	-	12.0	0.21

table 1 Calculation of the blade geometry of the VIRYA-2.22 rotor

No value for α_{th} and therefore for β_{th} is found for station F because the required C_l value can't be generated. The theoretical blade angle β_{th} varies in between 8.4° and 11.0°. If the blade angle is taken 8° at the blade tip and 12° at the blade root, the linearised blade angles are lying close to the theoretical values for the most important outer part of the blade. The central strip is twisted 12° to get the correct blade angle at the blade root. A sketch of the rotor and the PM-generator is given in figure 1.

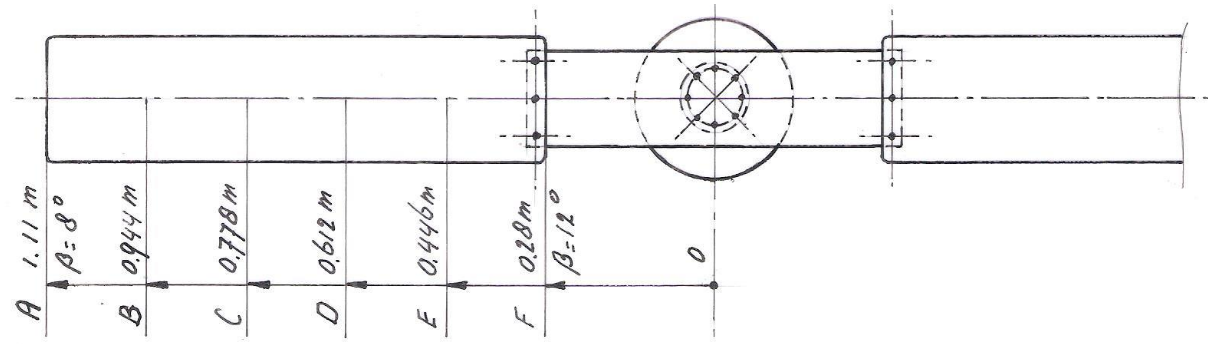

fig. 1 Sketch of the VIRYA-2.22 rotor and the PM-generator

4 Determination of the C_p-λ and the C_q-λ curves

The determination of the C_p-λ and C_q-λ curves is given in chapter 6 of KD 35. The average C_d/C_l ratio for the most important outer part of the blade is about 0.04. Figure 4.6 of KD 35 (for B = 2) and $\lambda_{opt} = 5$ and $C_d/C_l = 0.04$ gives $C_{p\ th} = 0.412$. The blade is just stalling at station F so only the part of the blade until 0.03 m outside station F is taken for the calculation of C_p. This gives an effective blade length k' = 0.8 m.
Substitution of $C_{p\ th} = 0.412$, R = 1.11 m and blade length k = k' = 0.8 m in formula 6.3 of KD 35 gives $C_{p\ max} = 0.38$. $C_{q\ opt} = C_{p\ max} / \lambda_{opt} = 0.38 / 5 = 0.076$.
Substitution of $\lambda_{opt} = \lambda_d = 5$ in formula 6.4 of KD 35 gives $\lambda_{unl} = 8$.
The starting torque coefficient is calculated with formula 6.12 of KD 35 which is given by:

$$C_{q\ start} = 0.75 * B * (R - ½k) * C_l * c * k / \pi R^3 \qquad (-) \qquad (6)$$

The average blade angle is 8°. For a non rotating rotor, the average angle of attack α is therefore 90° - 8° = 82°. The estimated C_l-α curve for large values of α is given as figure 5 of KD 398 for the 10 % cambered airfoil. It is assumed that this curve can also be used for the 7.14 % cambered airfoil at large angles of α. For α = 82° it can be read that $C_l = 0.28$. During starting, the whole blade is stalling. The central strip is also contributing somewhat to the starting torque. So now a blade length k = 0.9 m is taken.

Substitution of B = 2, R = 1.11 m, k = 0.9 m, $C_l = 0.28$ and c = 0.205 m in formula 6 gives that $C_{q\ start} = 0.012$. For the ratio in between the starting torque and the optimum torque we find that it is 0.012 / 0.076 = 0.158. This is acceptable for a rotor with a design tip speed ratio of 5. The starting wind speed V_{start} of the rotor is calculated with formula 8.6 of KD 35 which is given by:

$$V_{start} = \sqrt{\left(\frac{Q_s}{C_{q\ start} * ½\rho * \pi R^3}\right)} \qquad (m/s) \qquad (7)$$

The sticking torque Q_s of the generator is very low because there is no iron in the coils. The manufacturer says that it is less than 0.1 Nm. However this counts if no seal is mounted at the rotor shaft. A seal is required if the rotor shaft is placed horizontally like this is the case for the VIRYA-2.22. For the smaller generator with model number TGET260-0.15KW-500R it has been measured that the sticking torque is 0.004 Nm without a seal but 0.13 Nm with a new seal (see KD 5595 ref. 6). It was assumed that the sticking torque is 0.1 Nm when the seal is run in. The bigger generator of the VIRYA-2.22 has bigger bearings and a larger shaft (30 mm in stead of 25 mm) and to the sticking torque will be larger too. Assume $Q_s = 0.18$ Nm for a seal which has run in. Substitution of $Q_s = 0.18$ Nm, $C_{q\ start} = 0.012$, $\rho = 1.2\ kg/m^3$ and R = 1.11 m in formula 7 gives that $V_{start} = 2.4$ m/s.

This is acceptable for a 2-bladed rotor with a design tip speed ratio of 5 and a rated wind speed of 10 m/s. The generator is rectified in star and the unloaded Q-n curve will rise only a little at increasing rotational speed. The Q-n curve of the rotor for V = 2.4 m/s will rise faster and the real starting wind speed will therefore be about the same as the calculated value.

In chapter 6.4 of KD 35 it is explained how rather accurate C_p-λ and C_q-λ curves can be determined if only two points of the C_p-λ curve and one point of the C_q-λ curve are known. The first part of the C_q-λ curve is determined according to KD 35 by drawing a S-shaped line which is horizontal for $\lambda = 0$. Kragten Design developed a method with which the value of C_q for low values of λ can be determined (see report KD 97 ref. 7). With this method, it can be determined that the C_q-λ curve is rising slowly for low values of λ if a 7.14 % cambered airfoil is used. This effect has been taken into account and the estimated C_p-λ and C_q-λ curves for the VIRYA-2.22 rotor are given in figure 2 and 3.

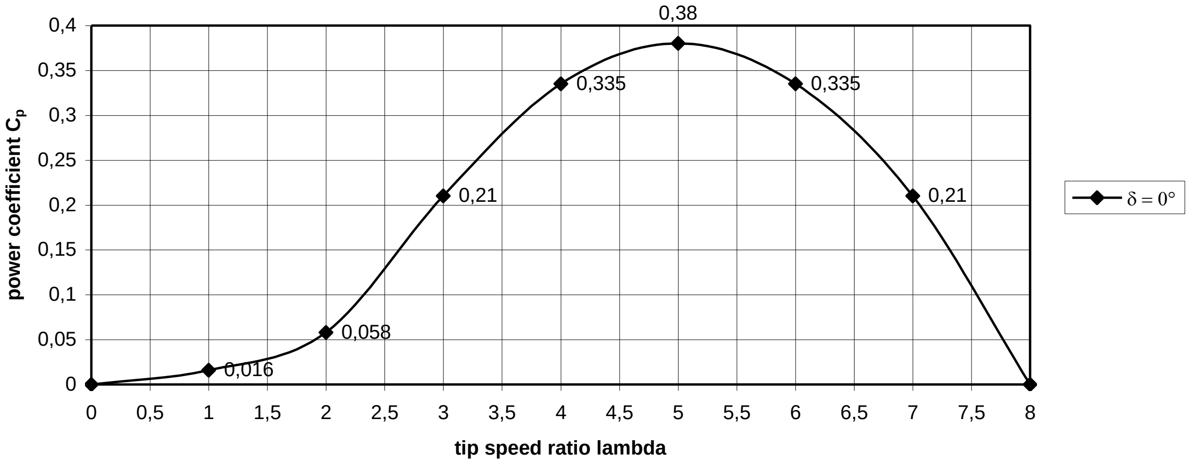

fig. 2 Estimated C_p-λ curve for the VIRYA-2.22 rotor for the wind direction perpendicular to the rotor ($\delta = 0°$)

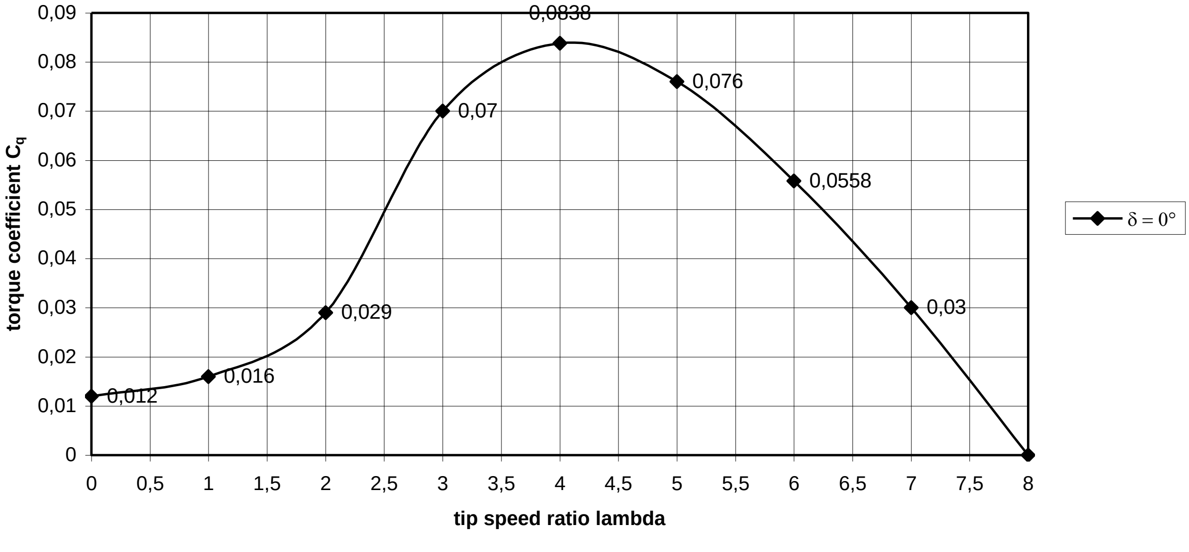

fig. 3 Estimated C_q-λ curve for the VIRYA-2.22 rotor for the wind direction perpendicular to the rotor ($\delta = 0°$)

5 Determination of the P-n curves and the optimum cubic line

The determination of the P-n curves of a windmill rotor is described in chapter 8 of KD 35. One needs a C_p-λ curve of the rotor and a δ-V curve of the safety system together with the formulas for the power P and the rotational speed n. The C_p-λ curve is given in figure 2. The δ-V curve of the safety system depends on the vane blade mass per area. The vane blade is made of 1 mm stainless steel. The rated wind speed for this vane blade is about 10 m/s. The estimated δ-V curve is given in figure 4.

The head starts to turn away at a wind speed of about 6 m/s. For wind speeds above 10 m/s it is supposed that the head turns out of the wind such that the component of the wind speed perpendicular to the rotor plane, is staying constant. The P-n curve for 10 m/s will therefore also be valid for wind speeds higher than 10 m/s.

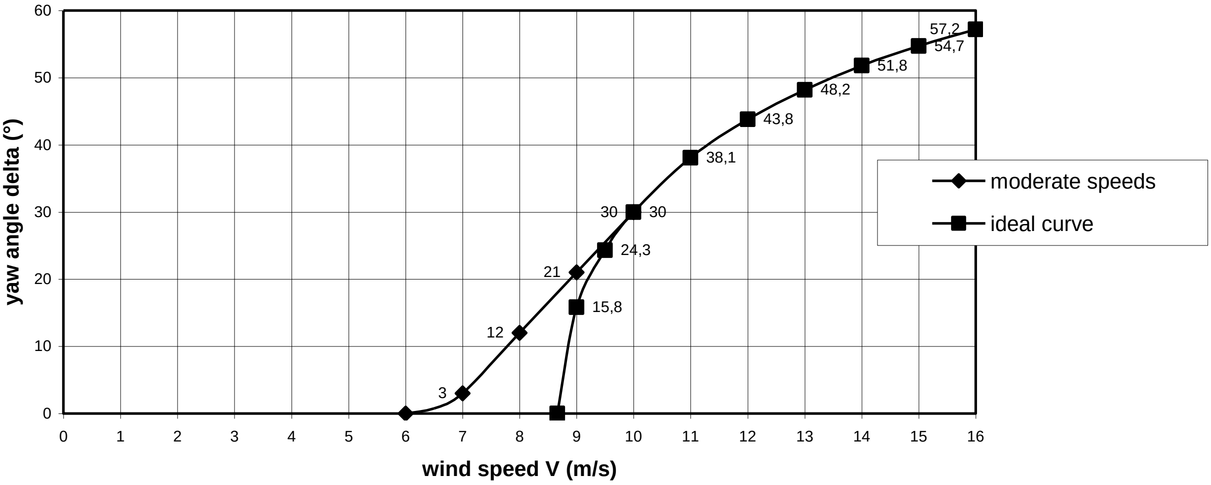

fig. 4 Estimated δ-V curve VIRYA-2.22 for a 1 mm stainless steel vane blade

The P-n curves are used to check the matching with the P_{mech}-n curve of the generator for a certain gear ratio i (the VIRYA-2.22 has no gearing so i = 1). Because we are especially interested in the domain around the optimal cubic line and because the P-n curves for low values of λ appear to lie very close to each other, the P-n curves are not determined for low values of λ. The P-n curves are determined for wind the speeds 3, 4, 5, 6, 7, 8, 9 and 10 m/s. At high wind speeds the rotor is turned out of the wind by a yaw angle δ and therefore the formulas for P and n are used which are given in chapter 7 of KD 35.

Substitution of R = 1.11 m in formula 7.1 of KD 35 gives:

$$n_\delta = 8.603 * \lambda * \cos\delta * V \qquad \text{(rpm)} \qquad (8)$$

Substitution of $\rho = 1.2$ kg / m^3 and R = 1.11 m in formula 7.10 of KD 35 gives:

$$P_\delta = 2.322 * C_p * \cos^3\delta * V^3 \qquad \text{(W)} \qquad (9)$$

The P-n curves are determined for C_p values belonging to λ = 3, 4, 5, 6, 7 and 8. (see figure 2). For a certain wind speed, for instance V = 3 m/s, related values of C_p and λ are substituted in formula 8 and 9 and this gives the P-n curve for that wind speed. For the higher wind speeds the yaw angle as given by figure 4, is taken into account. The result of the calculations is given in table 2.

		V = 3 m/s δ = 0°		V = 4 m/s δ = 0°		V = 5 m/s δ = 0°		V = 6 m/s δ = 0°		V = 7 m/s δ = 3°		V = 8 m/s δ = 12°		V = 9 m/s δ = 21°		V = 10 m/s δ = 30°	
λ (-)	C_p (-)	n (rpm)	P (W)	n (rpm)	P (W)	n (rpm)	P (W)	n (rpm)	P (W)	n_δ (rpm)	P_δ (W)	n_δ (rpm)	P_δ (W)	n_δ (rpm)	P_δ (W)	n_δ (rpm)	P_δ (W)
3	0.21	77.4	13.2	103.2	31.2	129.0	61.0	154.9	105.3	180.4	166.6	202.0	233.6	216.9	289.2	223.5	316.7
4	0.335	103.2	21.0	137.6	49.8	172.1	97.2	206.5	168.0	240.6	265.7	269.3	372.7	289.1	461.4	298.0	505.2
5	0.38	129.0	23.8	172.1	56.5	215.1	110.3	258.1	190.6	300.7	301.4	336.6	422.8	361.4	523.4	372.5	573.1
6	0.335	154.9	21.0	206.5	49.8	258.1	97.2	309.7	168.0	360.8	265.7	403.9	372.7	433.7	461.4	447.0	505.2
7	0.21	180.7	13.2	240.9	31.2	301.1	61.0	361.3	105.3	421.0	166.7	471.2	233.6	506.0	289.2	521.5	316.7
8	0	206.5	0	275.3	0	344.1	0	412.9	0	481.1	0	538.6	0	578.3	0	596.0	0

table 2 Calculated values of n and P as a function of λ and V for the VIRYA-2.22 rotor

The calculated values for n and P are plotted in figure 5. The optimum cubic line which can be drawn through the maximum of all P-n curves is also given in figure 5.

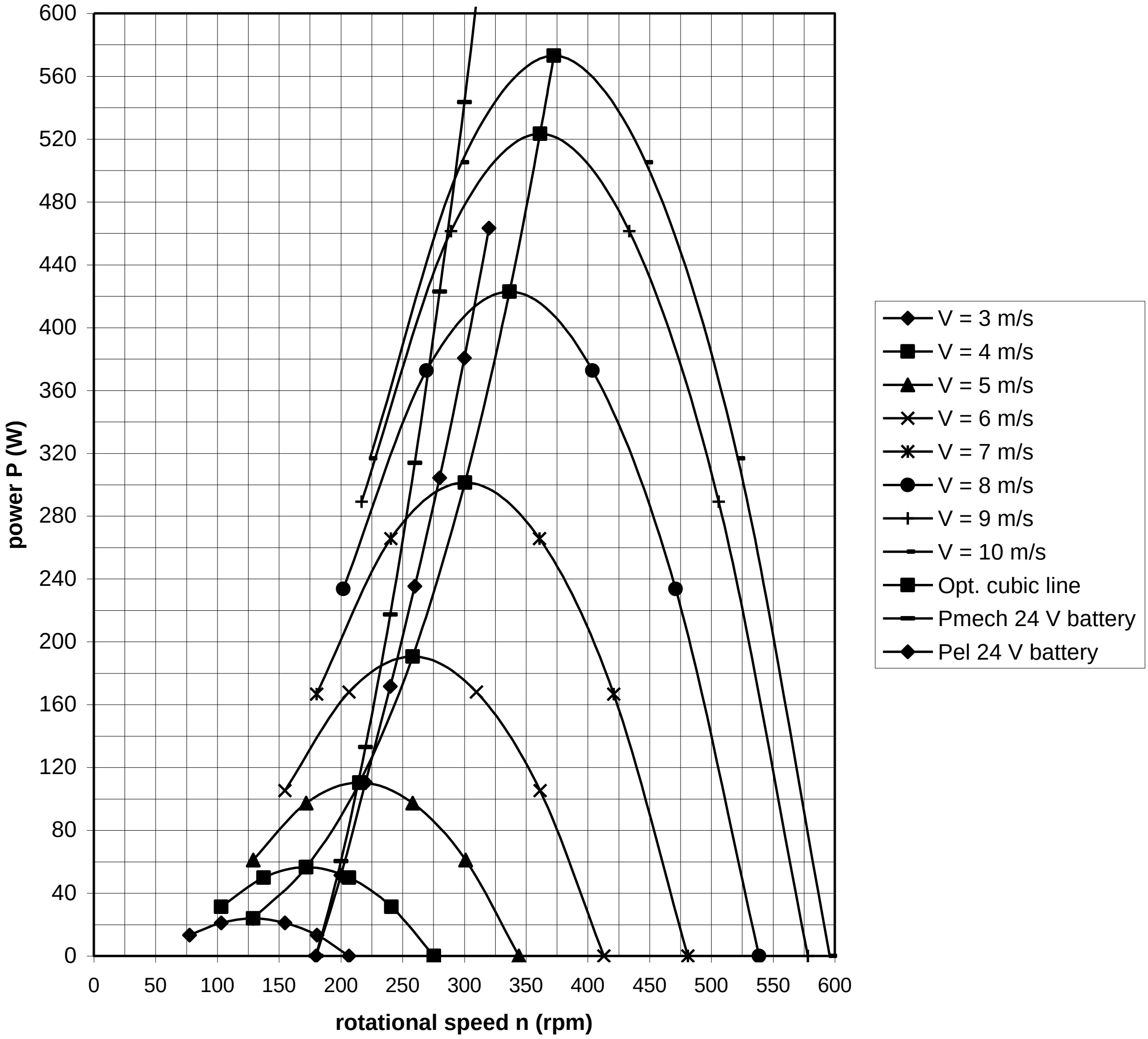

fig. 5 P-n curves of the VIRYA-2.22 rotor and optimum cubic line, estimated P_{mech}-n and P_{el}-n curves for 24 V battery charging

6 Estimation of the generator characteristics and the P_{el}-V curve

A data sheet of the chosen PM-generator can be found on the website of the company: Hefei Top Grand: www.china-topgrand.com following the path: Product – Outer rotor – page 2 – TGET260-0.5KW-350R. A copy of this data sheet is given in Appendix 1.

I have bought and tested a smaller generator of this company with model TGET165-0.15KW-500R and the measurements are given in report KD 595 (ref. 6). The electrical output at 500 rpm was smaller than the manufactures specification but technically the generator performed well and it has been tested in the field for about three years without problems. So I expect the same quality for the bigger type as used for the VIRYA-2.22.

In chapter 5 of the data sheet it is mentioned that the voltage is 28/56VDC. This doesn't mean that one generator can supply two different voltages. It means that the generator can be supplied with a 28 V winding or with a 56 V winding. The generator will be used for 24 V battery charging so one has to order the version with the 28 V winding! Two different voltage curves are presented in chapter 6 of the data sheet and one has to use the right picture.

The rated power is specified as 500 W at a rated rotational speed of 350 rpm. However, in the right voltage curve it can be seen that the loaded voltage is about 33 V for n = 350 rpm. So the rated voltage is 33 V and not 28 V as may be expected from chapter 5 of the data sheet! The voltage can't be read very accurately because the y-axis has a very strange diversion of the numbers in 0, 6, 12, 18, 25, 31 and 37 V.

The generator has a 3-phase winding which is connected in star. The star point is lying somewhere inside the generator so only the three phase wires are coming out of the hollow generator shaft. The specified voltage is the DC-voltage which means that one has used a 3-phase rectifier for the measurements. The rectifier isn't included in the generator so one has to select a 3-phase rectifier which can guide the maximum generator current. Information about rectification of a 3-phase current is given in report KD 340 (ref. 8).

The P_{el}-n curve for a fixed resistor load is about a parabola (see report KD 78, ref. 2) and the given P_{el}-n curve is about a parabola, so the load must have been a fixed resistor. The characteristics for a battery load are completely different than those for a resistor load but it might be possible to derive the characteristics for a 24 V battery load from the characteristics for a resistor load. The procedure how to do this requires calculation of the torque Q.

In the right voltage curve it can be seen that the loaded voltage is about 28 V for n = 300 rpm. In the power curve it can be seen that P_{el} = 380 W for n = 300 rpm. It is specified in the data sheet that the efficiency is at least 85 % or 0.85 but this is much too optimistic for a heavy load. For my measurements with the smaller generator it was found that the peak efficiency is about 0.72 and that the efficiency at the rated rotational speed is about 0.61 if the power loss in the rectifier is included in the generator efficiency (see KD 595 figure 7). The efficiency normally increases with the generator size and the power loss in the rectifier is relatively smaller for a 24 V battery load than for a 12 V battery load. Assume the efficiency is 0.7 for a rotational speed of 300 rpm. This gives a mechanical power P_{mech} = 380 / 0.7 = 543 W at n = 300 rpm. The relation in between the torque Q (Nm), the mechanical power P_{mech} (W) and the rotational speed n (rpm) is given by:

$$Q = 30 * P_{mech} / (\pi * n) \qquad \text{(Nm)} \qquad (10)$$

Substitution of P_{mech} = 543 W and n = 300 rpm gives that Q = 17.3 Nm at n = 300 rpm.

The maximum allowable charging voltage of a 24 V battery is about 28 V if the battery is full. So one needs a voltage controller + dump load to prevent that a full battery is over charged. A 200 W battery charge controller is described in a manual which can be found on my website at the bottom of the menu KD-reports (ref. 10). The power can be increased by connecting several modules in parallel.

Charging of a battery starts when the open DC-voltage of the generator is equal to the open battery voltage. The open battery voltage depends on the charging state of the battery but it is about 25.2 V for an almost full 24 V battery. The open voltage curve isn't given but based on the measurements for the smaller generator, it is assumed that the open voltage at a certain rotational speed is a factor 1.5 higher than the loaded voltage for a resistor load. This means that the open DC voltage is about 42 V for n = 300 rpm. As the open voltage increases linear to the rotational speed it means that the open voltage is about 25.2 V for n = 300 * 25.2 / 42 = 180 rpm. It is assumed that the torque Q is zero for the open voltage at n = 180 rpm.

In KD 78 it is found that the Q-n curve for a constant or an almost constant voltage is about a straight line. So the Q-n curve for a 24 V battery load is about a straight line through the point n = 180 rpm and Q = 0 Nm and the point n = 300 rpm and Q = 17.3 Nm. The torque can now easily be determined for other rotational speeds in between 180 rpm and 300 rpm and also for n = 320 rpm. The result is given in table 3. P_{mech} is calculated using formula 10 and is also given in table 3. The efficiency is about constant for a resistor load but not for a battery load. It is assumed that the efficiency is 0.85 for n = 200 rpm and 0.7 for n = 300 rpm.

n (rpm)	Q (Nm)	P_{mech} (W)	η (-)	P_{el} (W)
180	0	0	0	0
200	2.88	60.3	0.85	51.3
220	5.77	132.9	0.83	110.3
240	8.65	217.4	0.79	171.7
260	11.53	313.9	0.75	235.4
280	14.42	422.8	0.72	304.4
300	17.3	543.5	0.7	380.5
320	20.18	676.2	0.685	463.2

Table 3 Estimated values for Q, P_{mech}, η and P_{el} for a 24 V battery load

The values for P_{mech} and P_{el} as given in table 3 are now copied in figure 5. In figure 5 it can be seen that the the P_{mech}-n curve for a 24 V battery load is intersecting with the optimum cubic line at a wind speed of about 5 m/s. So the matching is perfect for this wind speed. For lower wind speeds, the rotor runs at a higher tip speed ratio than 5. For higher wind speeds, the rotor runs at a lower wind speed than 5. This reduces the sound production of the rotor at high wind speeds.

The matching is acceptable for wind speeds in between 3.5 and 10 m/s. However, this is only true if the real P_{mech}-n and P_{el}-n curves for a 24 V battery load are about identical to the estimated curves. If this generator is used in a windmill project, it is advised to buy one and to measure it on an accurate test rig for a real 24 V battery load or for a constant voltage of about 26 V. To see if the generator can also be used as a brake by making short-circuit (before the rectifier), it should also been measured for short-circuit

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 generated for that working point is found by going down vertically until the P_{el}-n curve is intersected. The electrical powers for a certain wind speed found this way are put in the P_{el}-V curve which is given in figure 6.

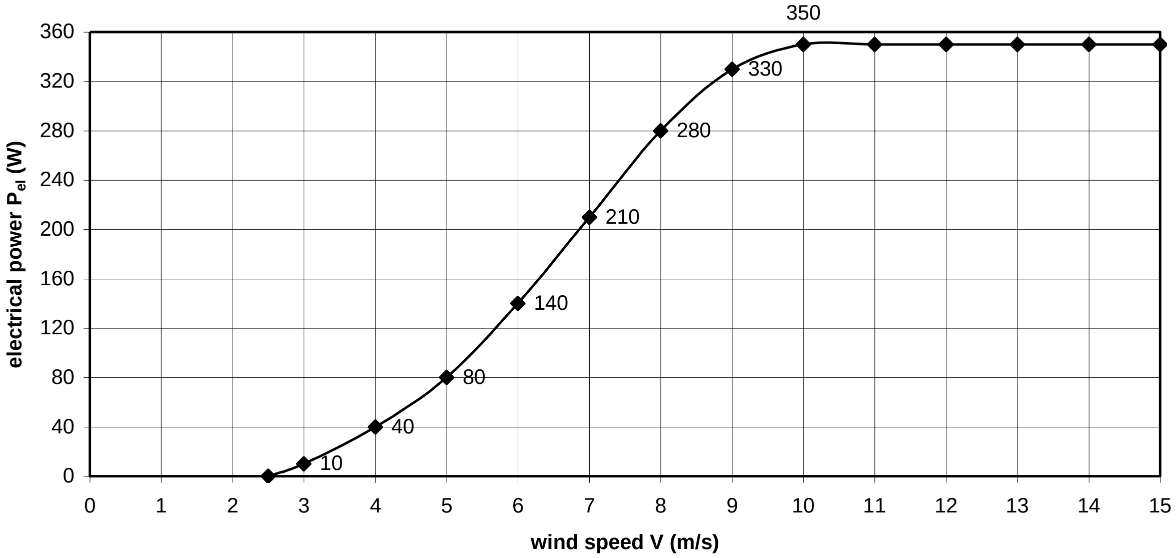

fig. 6   Estimated P_{el}-V curve VIRYA-2.22 for 24 V battery charging

In figure 6 it can be seen that the cut-in wind speed is about 2.5 m/s. In chapter 4 it was calculated that the starting wind speed is 2.4 m/s, so there is no hysteresis in the P_{el}-V curve. The maximum power is about 350 W for a wind speed of 10 m/s or higher. This is very good for a wind turbine with a rotor diameter of 2.22 m and a rated wind speed of 10 m/s. As the maximum power is about 350 W, one needs two 200 W battery charge controllers connected in parallel. The maximum DC current is about 350 / 27.6 = 12.7 A if the maximum charging voltage is limited up to 27.6 V. So one has to select a 3-phase rectifier which can conduct at least this current.

7 References

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

2 Kragten A. Measurements performed on a generator with housing type 5RN90L04V and a 4-pole armature equipped with neodymium magnets, March 2001, free public report KD 78, 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. Rotor design and matching for horizontal axis wind turbines, January 1999, reviewed February 2017, free public rapport KD 35, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

5 Kragten A. The 7.14 %, 10 % and 12.5 % cambered plate as airfoil for windmill rotor blades. Aerodynamic characteristics, geometry, moment of inertia I and moment of resistance W, November 2008, free public report KD 463, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

6 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 Kragten A. Determination of C_q for low values of λ. Deriving the C_p-λ and C_q-λ curves of the VIRYA-1.8D rotor, July 2002, free public report KD 97, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

8 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.

9 Kragten A. Manual of a 27.6 V, 200 W battery charge controller, March 2006, reviewed December 2016, free public manual, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

Appendix 1 Folder PM-generator Hefei Top Grand TGET260-0.5KW-350R

PRODUCT DETAIL

1. Model: TGET260-0.5KW-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

0.05-0.3 kw wind turbine; gasoline generators; hydroelectric generator

4. Shape Drawing

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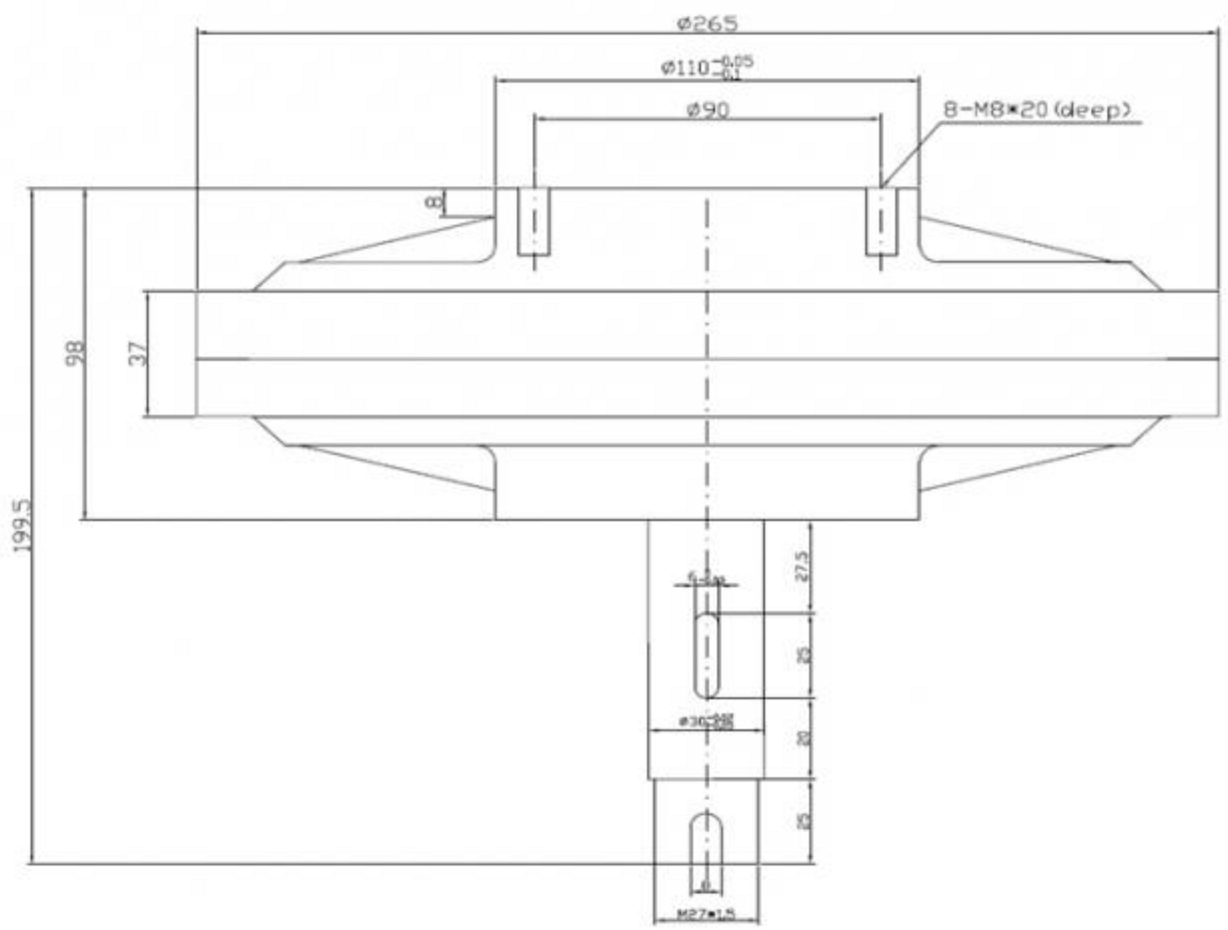
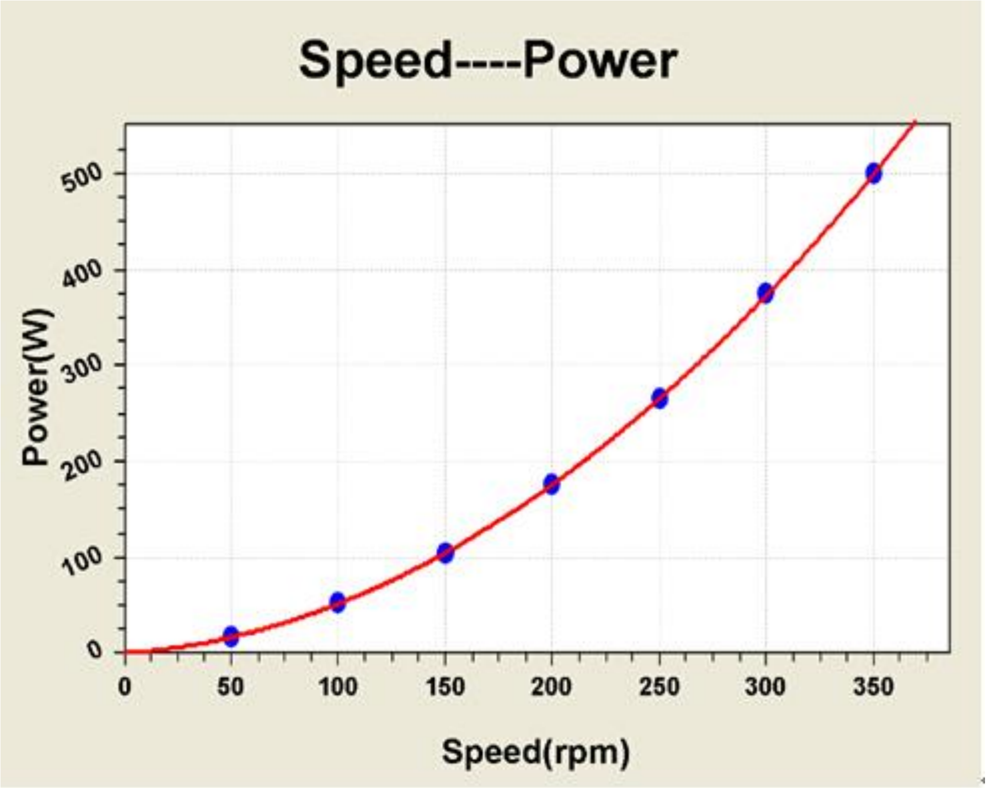


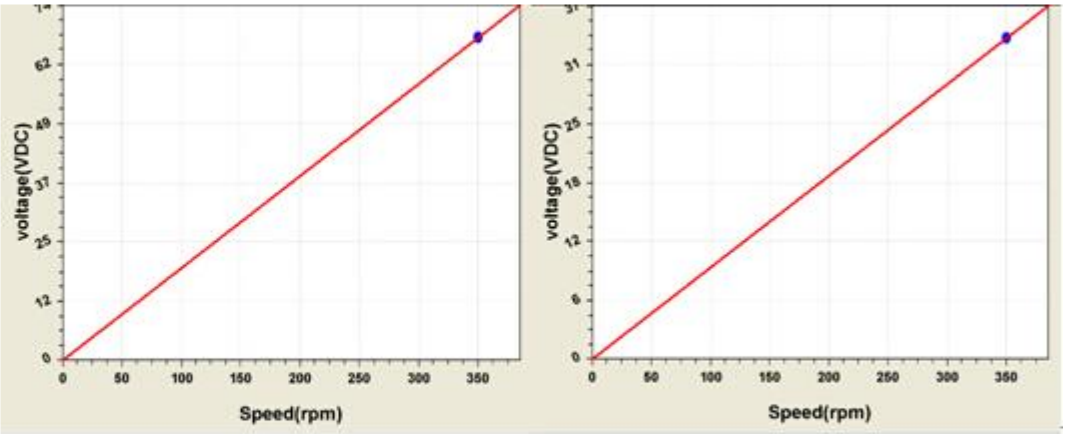
5. Performance Parameter

NO.	PARAMETER	UNITS	DATA
1	Rated power	KW	0.5
2	Rated speed	RPM	350
3	Rated voltage	V	56/28VDC
4	Rated Line Current		6.44/12.88
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	<0.1
12	Phase		Three phase
13	Structure		outer rotor
14	Stator		coreless
15	Rotor		Permanent magnet type (outer rotor)
16	Gen. Diameter	mm	265
17	Gen. Length	mm	199.5
18	Gen. Weight	kg	11
19	Shaft. Diameter	mm	30
20	Housing Material		Aluminum (Alloy)
21	Shaft Material		Steel
22	Gross Weight	KG	15

6. Curve Graph



ON-LOAD Power Curve



ON-LOAD Voltage Curve