Ideas about a 16-pole, 3-phase permanent magnet generator using the housing and winding of a 4-pole asynchronous motor frame size 100

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 The generator has not yet been built and tested.

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1 Introduction

One of the most critical parts of a small wind turbine is the generator. For my older range of VIRYA windmills, I have developed a range of PM-generators. These generators are derived from standard asynchronous 4-pole, 3-phase motors by replacing the original shaft and short-circuit armature by a stainless steel shaft and a mild steel armature which is provided by neodymium magnets. These generators (and several others types) are described in my public report KD 341 (ref. 1). These generators are very strong and have good characteristics. The sticking torque isn't fluctuating because the armature poles are making a certain angle with the axis. This facilitates starting of the rotor at low wind speeds.

The original shaft and armature is thrown away and a new stainless steel shaft and a new mild steel armature have to be made. Deep, inclined grooves have to be milled in the armature which needs special tools and is rather complicated and time consuming. 10 mm thick neodymium magnets have to be glued in the grooves. The whole generator is therefore rather difficult to manufacture and rather expensive.

I did several attempts to design a PM-generator which is simpler or cheaper and wrote KD-reports about every new idea. I have described radial flux and axial flux generators and generators with and without iron in the coils. The main disadvantage of a generator without iron in the coils is that this results in a big air gap. A big air gap reduces the magnetic flux flowing through the coils and therefore many thick and expensive magnets have to be used. The main disadvantage of a generator with iron in the coils is that this iron results in eddy currents and that the generator may have a strong peak on the sticking torque if the armature isn't designed properly. A large peak on the sticking torque results in a high starting wind speed if a fast running windmill rotor with a low starting torque coefficient is used.

There are several ways to reduce the peak on the sticking torque. I way to realise this for a 4-pole generator made from an asynchronous motor frame size 80 with 24 stator slots and using four magnets size 80 * 20 * 10 mm, is described in report KD 683 (ref. 2). In this report KD 718 it is researched if another way can be used for a bigger generator with 36 stator slots using a housing of frame size 100 and smaller magnets. An advantage of a 4-pole generator is that the standard 230/400 V, 3-phase motor winding can be used for 24 V or 48 V battery charging if the winding is rectified.

A starting point for this generator is that it can be made from the housing of a standard 4-pole asynchronous motor frame size 100. This has as advantage that the housing and the bearing covers are rather cheap because they are already manufactured in large quantities. Another important advantage is that a housing of an asynchronous motor is water tight if the shaft is provided by an IP-55 seal. A generator of frame size 100 has a shaft diameter at the front bearing of 30 mm and a shaft end with a diameter of 28 mm, a length of 60 mm and an 8 mm wide key groove. It can be used for a direct drive windmill rotor with a diameter of about 3 m. A PM-generator made from an asynchronous motor has a magnetic flux which is radial at the air gap in between the armature and the stator stamping, so this generator will be of the type "radial flux".

2 Description of the 16-pole PM-generator

2.1 General

It is chosen to take an asynchronous motor in which a stator stamping of the German manufacture Kienle & Spiess is used. Information about dimension of stator stampings of this manufacture are given on the website: www.kienle-spiess.de. The chosen stator stamping has the code: IEC 100/4.944. The outside diameter is 150 mm, the inside diameter is 90 mm. This stamping is used for a 3 kW, 4-pole motor and the length of the stator stamping is 120 mm for this motor. The stamping has 36 slots, so in between these slots there are 36 stator poles.

The stamping has six 4.07 mm holes at a pitch circle of 144 mm. The manufacturer which uses this stamping of Kienle & Spiess for its 3 kW motor has not yet been selected.

It is chosen to use this stamping for an armature with four magnetic poles. A 4-pole armature has normally two north and two south poles. The angle in between the heart of a north pole and the heart of a south pole is 90° for a 4-pole generator. This means that the optimum angle in between two legs of a stator coil is 90° too. However, it isn’t possible to use this angle for all coils if the stator stamping has 36 slots. This problem is solved by using three coils which are lying within each other and for which the inner coil has an angle of 70°, for which the middle coil has an angle of 90° and for which the outer coil has an angle of 110°.

If the armature pole angle is chosen 90°, it means that the generator will normally get 36 preference positions per revolution. The armature will get a preference position when the magnetic flux in between armature and stator flows easiest. This is the case when there is a maximum overlap in between an armature pole and some of the stator poles.

If the armature poles are inclined with an angle such that there is just one stator pole pitch overlap in between the left and the right side of the armature pole, this problem is solved. However, inclined armature poles can only be gained if the magnets are placed in deep narrow grooves with the magnet area tangential and if there is magnetic isolation in between the north and the south poles. This procedure is used for the older VIRYA generators and the armature construction is explained in chapter 4 of report KD 341 (ref. 1).

2.2 Description of the armature

This new generator has an armature which is made from a 90 mm diameter and 120 mm long steel bush which is pressed on the original motor shaft. The bush is turned to a diameter of 89.4 mm after pressing. It is chosen that the magnets are positioned in eight 15 mm wide and 5.7 mm deep grooves with the magnet area radial and that the grooves are made in parallel to the armature axis. The angle in between the heart of the grooves is 45°. So a short and stiff 15 mm diameter cutter can be used. Three magnets size 40 * 15 * 5 mm are glued in each groove with epoxy or anaerobe glue. So totally 24 magnets are needed for one armature. In between each row of magnets there is a row of poles which is formed by the steel armature bush.

The magnets are glued in such a sequence that the armature works well in combination with the original 230/400 V, 3-phase, 4-pole stator motor winding. This is realised by using two rows of magnets with the north poles to the outside for one magnetic north pole and two rows of magnets with the south poles to the outside for one magnetic south pole. As one magnetic pole contains also two rows of the steel bush, it has totally four poles. So mechanically, the armature has totally sixteen poles. However, because four rows of the same poles are lying against each other, physically it is still a 4-pole armature and so it can be used in combination with the winding of a 4-pole motor.

So the armature has totally sixteen poles in the following sequence: N1, N2, N3, N4, S1, S2, S3, S4, N5, N6, N7, N8, S5, S6, S7 and S8. The odd pole numbers are for the poles formed by the magnets. The even pole numbers are for the poles formed by the steel armature bush.

At each side of a 15 mm wide magnet groove there is a 2.5 mm wide and 3.7 mm deep groove to make that the poles which are formed by the armature bush also have a width of about 15 mm and to prevent magnetic short-circuit in between a north and a south pole at the sides of a magnet. These grooves can be made with a 20 mm cutter.

The stator has 36 slots so it has 36 poles and so the stator pole angle is 10°. The stator poles are numbered 1 – 36. In figure 1, the armature is drawn such that the heart of north pole N1 is just opposite stator pole no. 1.

The armature will therefore have a preference position for the drawn position. However, it will have a preference position for N2 if the armature has rotated 2.5° left hand. It will have a preference position for N3 if the armature has rotated 5° left hand. It will have a preference position for N4 if the armature has rotated 7.5° left hand. This means that the armature will have a preference position every 2.5° and so it will have 144 preference positions per revolution. This seems enough to flatten the peak on the sticking torque up to an acceptable low value.

However, there is one important condition and that is that it isn't allowed to use a stator stamping with four outside grooves. Thin strips with bent ends, lying in these grooves, are used to connect all stampings together. These stampings are generally used in India. Four outside groves in the stator stamping make that the armature will get four strong preference positions per revolution for the position of the armature for which the magnetic flux in the stator is least hindered by the four outside grooves. Kienle & Spiess also supplies a stator stamping with four outside grooves with code: IEC 100/4.936 so this stamping should not be chosen! The six 4.07 mm holes at a pitch circle of 144 mm in the stamping IEC 100/4.944 of Kienle and Spiess may cause six small extra preference positions per revolution. These preference positions can be prevented by placing of a mild steel rod with a diameter of 4 mm and a length of 120 mm in each hole.

The neodymium magnets are supplied by the Polish company Enes Magnets website: www.enesmagnets.pl. The magnets of this company are rather cheap if compared to magnets with the same volume of other magnet suppliers. The magnets size 40 * 15 * 5 mm have quality N38. The current price for one magnet is € 2.85 including VAT but excluding transport if at least 70 magnets are ordered. 24 magnets are needed for one generator, so the magnet costs for one generator are about € 70 which is rather cheap for this generator size.

The armature is made of a 120 mm long mild steel bush with an outer diameter of 90 mm. The armature is pressed on the original motor shaft such that the sides of the armature coincide with the sides of the stator stamping. The bearings and the original short-circuit armature have to be removed first from the shaft if an original motor shaft is used. The original short-circuit armature has an inner diameter of 36 mm. The original motor shaft is provided with small grooves in the direction of the axis to guarantee a strong press fitting. As the original stator stamping is made of very soft steel, it might be required to give the new armature an inside diameter which is a little larger than 36 mm, so for instance 36.1 mm, otherwise the required pressing force may be too high. The armature is turned to a diameter of 89.4 mm after pressing it on the shaft. This must be done such that the outside is exactly concentric to the two bearing seats. So the air gap in between the poles which are formed by the armature bush and the stator becomes (90 – 89.4) / 2 = 0.3 mm.

The 15 mm wide grooves for the magnets are made that deep that the distance in between the bottom of the groove and the axis of the shaft is 39 mm. This means that the depth of the groove measured from the outside of the armature is 44.7 – 39 = 5.7 mm. The magnets are not jutting out of the armature for this groove depth. The average air gap at the magnets is somewhat larger than the air gap at the poles formed by the armature bush but this is no problem.

The front bearing cover at the shaft side has an oil seal. No fan is needed and so the back bearing cover is closed and the back bearing cover therefore has no seal. The shaft has to be shortened if the back bearing cover is closed. The bearings have an internal rubber seal at both sides. The space in between the front bearing and the shaft seal is filled with grease to create an extra barrier against the entrance of water and dust. So the original motor shaft can be used and stainless steel isn't needed for its anti magnetic qualities as it is the case for the older VIRYA generators with inclined magnet grooves. A cross section and a side view of the generator armature are given in figure 1 at chapter 2.3.

Instead of removing the complete original short-circuit armature, one can also use a bush made of seamless steel pipe size 90 * 10. The armature is turned to about 69.8 mm and a 120 mm long bush is glued to the pipe by anaerobe glue. The outside is turned to 89.4 mm.

2.3 Description of the stator

The stator stamping is pressed in the aluminium generator housing. The stator stamping has 36 slots in which the coils are laid. In between the 36 slots we have 36 stator poles which are numbered 1 – 36.

Two slots are used for one coil, so 18 coils can be laid in 36 slots. Every phase has six coils for a 3-phase winding. The slots are provided with a thin slot isolation. After mounting of the coils, a slot cap is shifted in each slot to prevent that the coils can come out of the slots and touch the rotating armature. It will be needed so soak the whole assembly of coils in liquid lacquer to prevent vibration of the wires if a new winding is laid. In chapter 2.1 it was already explained that three coils of one phase are positioned within each other.

The winding is a so called 2-layers winding. This means that the three bundles of three coils U1, U2 and U3, V1, V2 and V3 and W1, W2 and W3 are laid in the first layer. The coil heads of these nine coils are bent to the outside to make place for the nine coils of the second layer U4, U5 and U6, V4, V5 and V6 and W4, W5 and W6. The three coils of a certain phase in one layer are always connected in series because the voltage generated in each of the coils isn't the same. The three coils of the first layer can be connected in series with the three coils of the second layer or they can be connected in parallel. But all six coils of a standard 230 / 400 V winding are normally connected in series.

The three coils of a coil bundle of one phase are made outside the generator. The first layer with three coils has an end labelled A and an end labelled B. The second layer with three coils has an end labelled C and an end labelled D. So the ends B and C are normally soldered to each other. The soldering point is isolated and is lying somewhere on the coil heads. The both ends A and D of each phase are connected to a terminal with six tags in a way as this is normally done for a 3-phase winding.

The winding can be connected in star or in delta. For star connection, the three coil ends labelled A are connected to each other by brass strips and are forming the star point. The three coil ends labelled D are guided to the three contacts of a 3-phase rectifier. It is also possible to connect the winding in delta by using three brass strips in parallel and this reduces the voltage by a factor $\sqrt{3}$.

Which way of rectification has to be used depends on the choice of the windmill rotor and the battery voltage. A standard 230 / 400 V winding will give a rather high voltage already at low rotational speeds and so it won't be possible to use the generator for 12 V battery charging for the original winding. The original winding might be useful for 24 V battery charging if the winding is rectified in delta and for 48 V battery charging if the winding is rectified in star.

The standard 230 / 400 V winding can be modified into a 115 / 200 V winding if the coil bundles of the first and second layer of a certain phase are connected in parallel in stead of in series. So coil end C is connected to coil end A and coil end D is connected to coil end B. This procedure is explained in detail in report KD 341 (ref. 1). A modified 115 / 200 V winding can be used for 24 V battery charging if the winding is rectified in star and for 12 V battery charging if the winding is rectified in delta. But a 12 battery voltage will result in very large maximum currents and so in high cable losses in between the generator and the battery. So 12 V battery charging isn't advised for this rather large PM-generator.

A prototype of the generator has to be measured and a windmill rotor with the correct rotor diameter and design tip speed ratio has to be chosen for correct matching (see chapter 4).

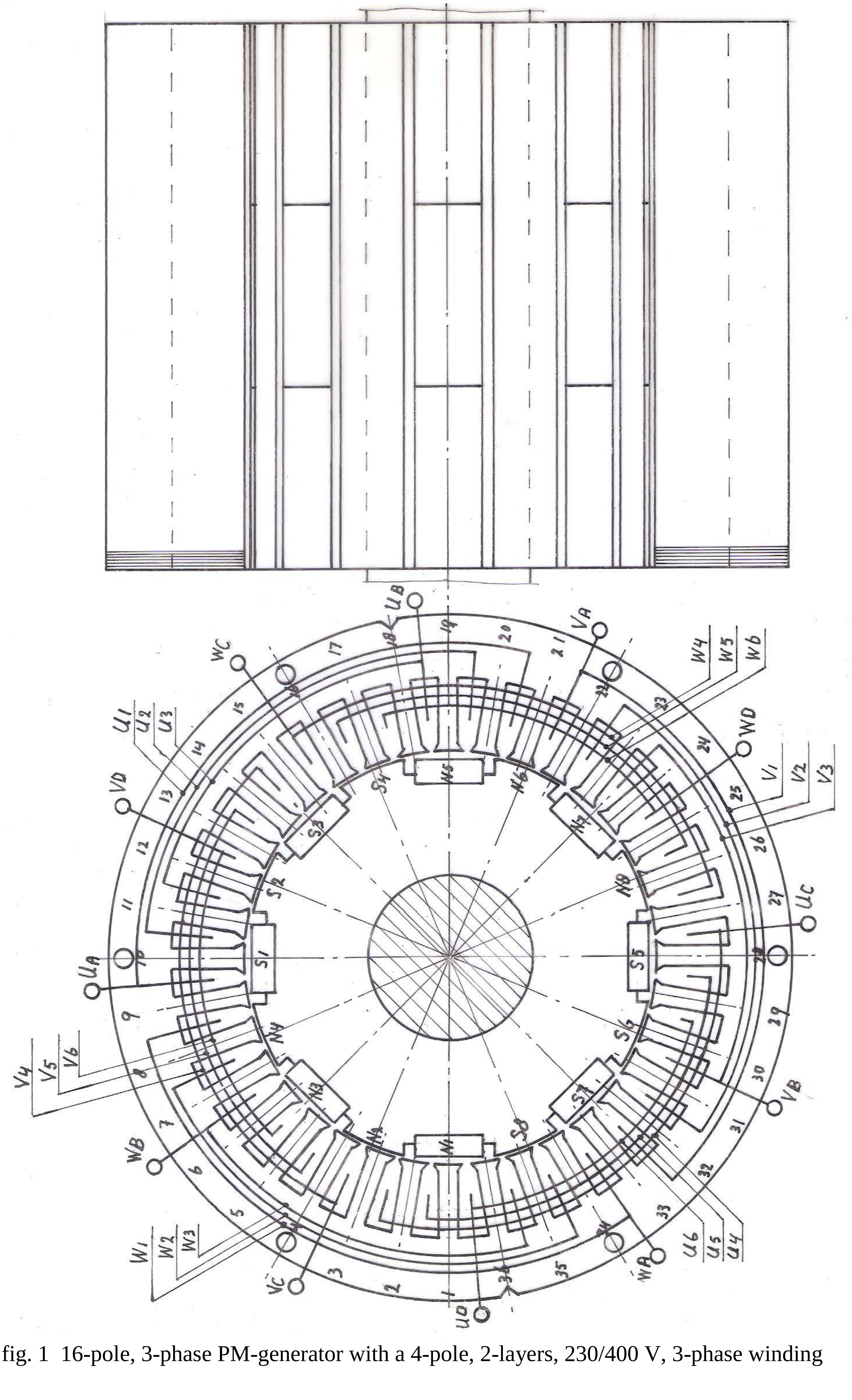

fig. 1 16-pole, 3-phase PM-generator with a 4-pole, 2-layers, 230/400 V, 3-phase winding

3 Determination of the flux density in the air gap

A part of a magnetic loop is flowing inside the armature and a part is flowing inside the stator. Four magnetic loops are coming out of a normal 4-pole armature. Two loops are turning left hand and two loops are turning right hand. However, eight magnetic loops are coming out of this special 16-pole armature. Four loops are turning left hand and four loops are turning right hand (see figure 2). Two left hand turning loops will be followed.

The magnetic flux coming out of the magnet of north pole N1 flows through the large air gap t_3 into the stator stamping. Next it makes a left hand bend of 202.5°. Next it flows through the small air gap t_2 and enters the south pole S8. Next it flows into the steel armature bush, making a left hand bend of 157.5° and enters the magnet of the north pole N1 again. So this magnetic loop flows through one magnet and the two air gaps t_2 and t_3.

The magnetic flux coming out of north pole N2 flows through the small air gap t_2 into the stator stamping. Next it makes a left hand bend of 247.5°. Next it flows through the large air gap t_3 and enters the magnet of south pole S7. Next it flows into the steel armature bush, making a left hand bend of 112.5° and enters the north pole N2 again. So also this magnetic loop flows through one magnet and the two air gaps t_2 and t_3. The only difference is that this second loop is longer than the first one as it lies around the first one.

A magnet has a thickness t_1 = 5 mm. As the glue layer is very thin, it is assumed that there is no air gap in between the inside of the magnet and the bottom of the groove.

The stator stamping has an inside diameter of 90 mm. It is assumed that the armature is turned at a diameter of 89.4 mm at the south poles. So the air gap at the poles which are formed by the armature bush t_2 = 0.3 mm. The air gap opposed to the magnets is maximal at the heart of the magnet and minimal at both sides. The groove depth is chosen such that there is a distance of 39 mm from the bottom of the groove up to the shaft axis. This means that the air gap at the heart of the 5 mm thick magnet is 45 – (39 + 5) = 1 mm. The air gap at the sides of the magnet is about 0.37 mm so the magnets don’t jut out of the armature. The average air gap is more than half the mathematical average because the air gap is moon shaped. Assume that the average air gap at the north poles t_3 = 0.8 mm.

The flux density in the air gap is calculated by formula 5 from report KD 341 for a PM-generator with tangential orientation of the magnets. A simpler formula can be derived for this PM-generator with radial orientation of the magnets if the magnetic resistance of the iron is neglected and if it is assumed that the magnetic resistance of the magnets is the same as for air. Formula 1 of KD 341 changes into:

$$B_{r\,eff} = B_r * t_1 / (t_1 + t_2 + t_3) \quad \text{T} \tag{1}$$

For radial positioning of the magnets, the pole area is the same as the magnet area. So it isn’t necessary to compare the magnet area with the pole area as it is required for tangential positioning of the magnets. So formula 1 can be used directly to calculate the flux density in the air gap. The used magnets with quality N38 have a remanence B_r of about 1.24 T. Substitution of B_r = 1.24 T, t_1 = 5 mm, t_2 = 0.3 mm and t_3 = 0.8 mm in formula 1 gives that $B_{r\,eff}$ = 1.02 T.

In KD 341 it is assumed that the stator stamping is saturated if the calculated flux density in the air gap is larger than 0.9 T. So it can be expected that the generator is saturated and so the maximum possible torque level is gained. The stator stamping can be saturated at the spokes in between the slots or at the bridge in between the bottom of the slots and the outside of the stamping. The stamping is designed for a 4-pole motor and it is used for a generator with a 4-pole winding. So if the stator stamping is saturated, it can be saturated at the spokes, at the bridge or at both.

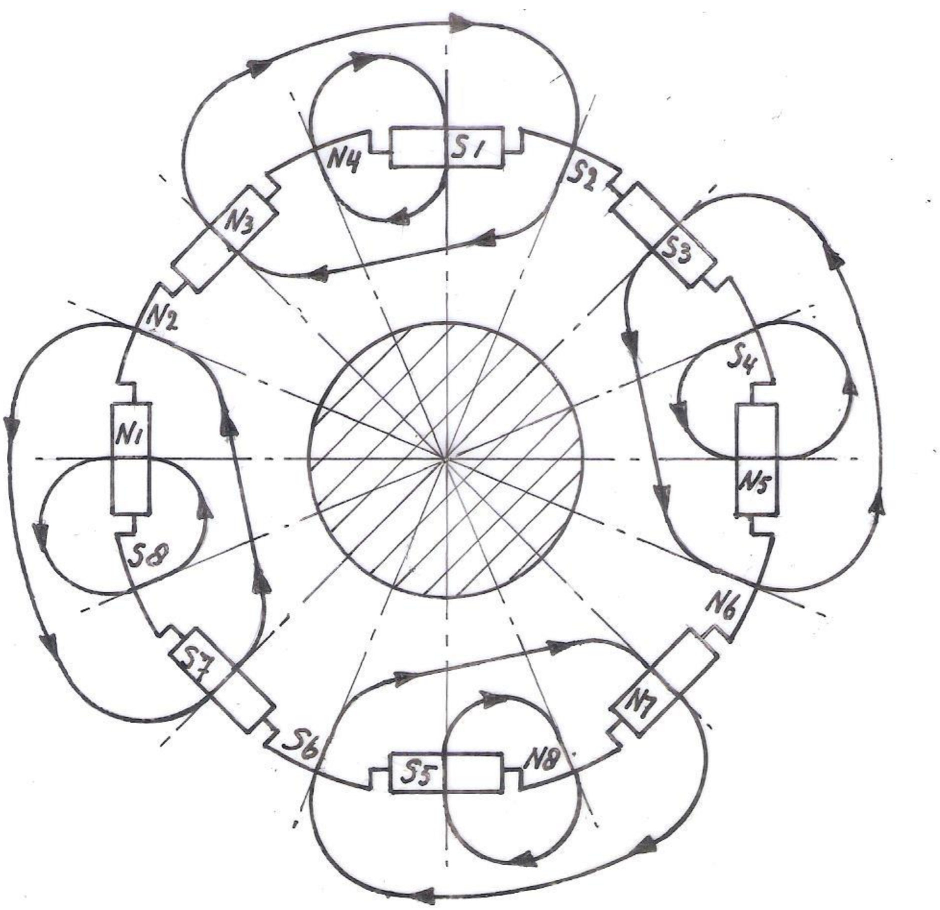

fig. 2 16-pole armature with four left hand and four right hand magnetic loops

4 Checking if the standard winding can be used

The standard winding of a 4-pole motor is meant for a 3-phase 230 / 400 V grid with a frequency of 50 Hz. It might be possible to use the PM-generator with this standard winding for 24 V or for 48 V battery charging. To verify this, one needs a test rig with which it is possible to measure the torque, the rotational speed, the voltage and the current. I have used a sophisticated test rig of the University of Technology Eindhoven for measuring my older VIRYA generators but this was done long ago. I have also developed a simple private test rig for very small axial flux generators but this test rig is much too small for this 4-pole generator. I will not perform measurements for this new generator.

First the generator is connected in star and the P_{mech}-n and P_{el}-n curves are determined for a 48 V battery of sufficient capacity or for a battery charge controller which is adjusted at a constant voltage of 52 V. A voltage of 52 V is about the average charging voltage for a 48 V battery. Next the generator is connected in delta and the P_{mech}-n and P_{el}-n curves are determined for a 24 V battery of sufficient capacity or for a battery charge controller which is adjusted at a constant voltage of 26 V. A voltage of 26 V is about the average charging voltage for a 24 V battery. Rectification of a 3-phase winding is explained in KD 340 (ref. 3).

Next the P-n curves of the chosen windmill rotor are determined for different wind speeds and these curves are drawn in a P-n graph. A windmill rotor has a certain optimum cubic line which can be drawn through the tops of the P-n curves of the rotor for different wind speeds. The formula for the optimum cubic line is given in chapter 8 of report KD 35 (ref. 4). The optimum cubic line is also drawn in the P-n graph with the generator measurements. If the correct parameters have been chosen for the windmill rotor, the P_{mech}-n curve of the generator for 52 V star and for 26 V delta will have a good matching with the optimum cubic line of the chosen rotor.

Good matching means that both curves have two points of intersection which are not lying far apart. If there is no good matching for none of the P_{mech}-n curves of the generator, one has to change the parameters of the windmill rotor (matching is explained in chapter 8 of report KD 35 ref. 4).

It is expected that the matching is good for the VIRYA-3B3 rotor using the generator with the original 230/400 V winding for 48 V battery charging rectified in star and for 24 V battery charging rectified in delta. The P-n curves of this rotor are given in figure 4 of report KD 484 (ref. 5). This figure is copied as figure 3 but the P_{mech}-n curve, the P_{el}-n curve and the P-n curve for short-circuit in star and delta of the original VIRYA-3B3 generator are removed.

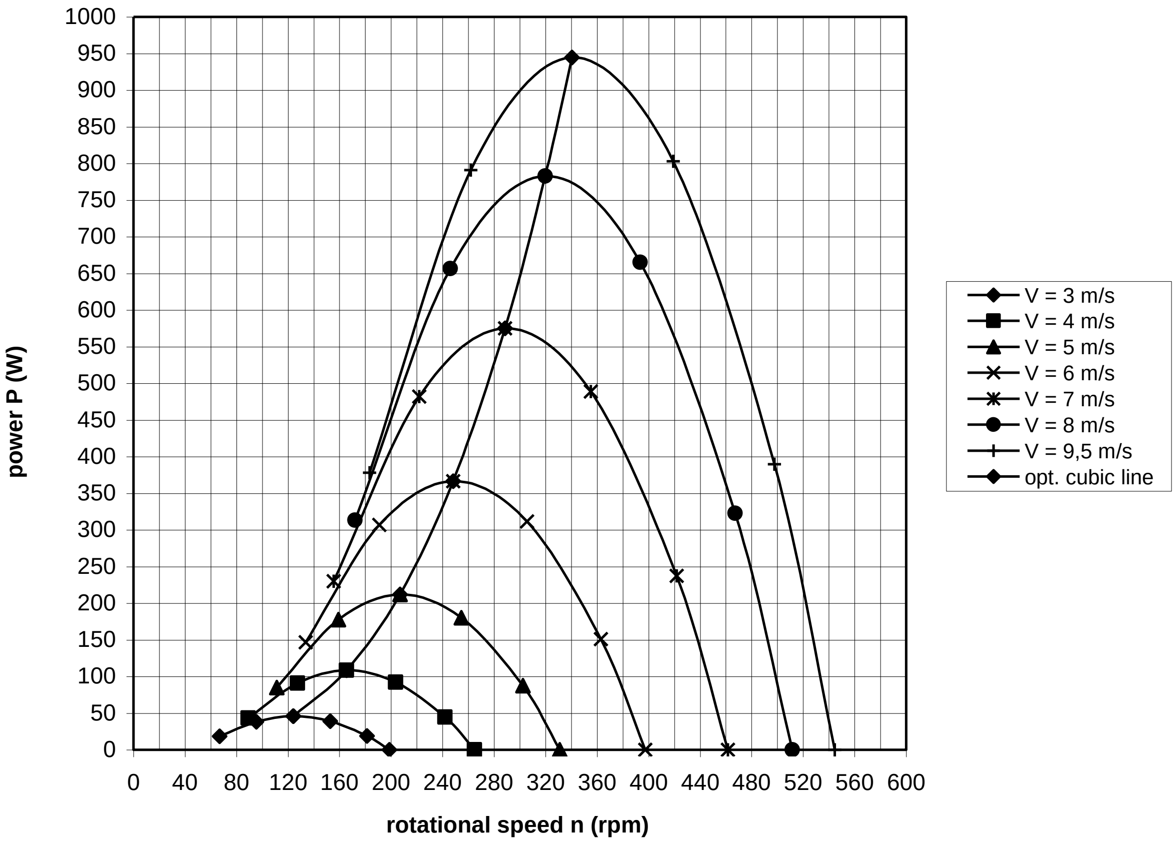

fig. 3 P-n curves of the VIRYA-3B3 rotor for V_{rated} = 9.5 m/s and optimum cubic line

The original VIRYA-3B3 generator has frame size 90 and a 25 mm tapered shaft. So the generator hub has to be modified for a 28 mm cylindrical shaft and the generator bracket of the head has to be modified for a generator of frame size 100.

The disadvantage of delta rectification is that the sticking torque of the generator is rising faster at increasing rotational speed than for star rectification. This is because higher harmonic currents can circulate in the winding for delta rectification. Delta rectification can only be used if the starting torque coefficient of the chosen rotor is high enough. The advantage of delta rectification is that the maximum breaking torque is larger. So stopping the rotor by making short-circuit in the winding, can better be done for connection in delta. Short-circuit is star is the same as short-circuit in delta if the star point is short-circuited too.

The short-circuit switch has to be mounted as close as possible to the generator. So mounting on a box in the tower foot is the best place. The 3-phase rectifier has to be mounted in the box. A 4-wires elastic cable connects the generator to the box. A massive 2-wires cable can be used to connect the rectifier to the batteries and the battery charge controller.

5 Checking of the strength of the glue in between magnets and armature

The neodymium magnets are glued in the magnet grooves. As a prototype has not yet been built and tested, it is not proven that the glue is strong enough. However, I have built several other PM-generators with glued magnets and never one of the magnets came loose. But the quality of the glue connection depends on the type of glue which is used and on the cleaning of the grooves before gluing. The history of the development of the VIRYA generators is given in report KD 341 (ref. 1). For the oldest 12-pole generators using ferroxdure magnets, I have used industrial epoxy glue. For the later 4-pole generators using neodymium magnets, I have used a special anaerobe glue type ThreeBond 1132.

Anaerobe glue has some advantages above epoxy glue which are:

1 The glue hardens only in the air gap. So superfluous glue can be removed easily if the glue in the air gap has hardened.
2 The glue starts hardening in about a quarter of an hour in the air gap. So if clamps are used to press the magnets in the grooves, these clamps can be removed soon. The final strength is gained only after some hours.
3 Anaerobe glue can have a much higher temperature than epoxy glue. No heat is generated in the armature but some of the heat generated in the stator is radiated to the armature. Most epoxy glues have lost all strength at about 100 °C. So the armature temperature may become too high for epoxy glue if the generator is used long at its maximum power.
4 Anaerobe glue is thinner than normal epoxy glue. So if the magnet is pushed in the groove, the glue layer at the bottom of the groove will become thinner and so the magnet position is defined more precisely.

The disadvantage of most anaerobe glues is that it hardens only in very small gaps. But the chosen type ThreeBond 1132 hardens in an air gap of maximum 0.5 mm and this is certainly acceptable. The grooves must be cleaned very well and one must use the correct solvent which is acetone or alcohol. One should not use refined petrol or thinner as these solvents have a negative influence on the hardening time and the final strength of the glue!

ThreeBond 1132 is supplied by the Dutch company Viba website: www.viba.nl. I have bought a 250 gram tube which costs about € 54 excluding VAT and costs of transport in 2021. This glue can be used in between temperatures of – 60 °C and 200 °C. The maximum shearing stress lies in between 14 and 17 N/mm^2.

A magnet is pulled in a groove by the magnetic holding force and pushed out of the groove by the centrifugal force and may be also by the magnetic force caused by currents in the stator. It is assumed that no magnetic force is active and so only the centrifugal force is acting on a magnet.

The centrifugal force depends on the rotational speed. The highest rotational speed is gained if the windmill rotor is turning unloaded. Normally this doesn't happen but the worst case scenario is taken. In figure 3 it can be seen that the maximum unloaded rotational speed for the VIRYA-3B3 rotor is about 550 rpm but lets take n_{max} = 600 rpm. The centrifugal force F_c is given by:

$$F_c = m * r * \omega^2 \quad (N) \qquad (2)$$

m is the mass of one magnet in kg. r is the radius of the centre of gravity of a magnet in m. ω is the angular velocity in rad/s. The relation in between the angular velocity and the rotational speed n in rpm is given by:

$$\omega = \pi * n / 30 \quad (rad/s) \qquad (3)$$

(2) + (3) gives:

$F_c = m * r * \pi^2 * n^2 / 900$ (N) (4)

One magnet has as dimensions 40 * 15 * 5 mm. So the volume of one magnet is 3000 mm^3 = 3 cm^3. Neodymium magnets have a density of about 7.5 gram/cm^3. So the mass of one magnet is 3 * 7.5 = 22.5 gram = 0.0225 kg.

The centre of gravity of a magnet lies in the centre of the magnet so at a distance of 2.5 mm from the bottom of a groove. The bottom of a groove lies at a distance of 39 mm from the armature axis. So the centre of gravity of a magnet lies at 39 + 2.5 = 41.5 mm from the axis of the armature. This gives that r = 0.0415 m. Substitution of m = 0.0225 kg, r = 0.0415 m and n = 600 rpm in formula 4 gives that F_c = 3.7 N which is very low.

The magnet makes contact with the bottom of the groove but also with the 2 mm high sides of the groove. Let’s forget the sides. The contact area A at the bottom of the groove is 40 * 15 = 600 mm^2. So the pulling stress in the glue is 3.7 / 600 = 0.0062 N/mm^2 which is very low. The allowable pulling stress isn’t given and it may be somewhat smaller than the maximum shearing stress which is at least 14 N/mm^2. Assume that the allowable pulling stress is 10 N/mm^2. The calculated stress is a factor 1613 lower!

So this calculation shows that the glue in between magnets and armature is absolutely strong enough and that a much higher rotational speed than 600 rpm is allowed.

6 Ideas about a bigger 16-pole PM-generator frame size 132

It seems possible to use the same principle of the 16-pole PM-generator as described in chapter 2, for a bigger generator using a 4-pole housing frame size 132M and bigger magnets. Frame size 132M is used for a 7.5 kW, 4-pole motor. A stator stamping of Kienle & Spiess used for a 7.5 kW, 4-pole motor, has an outside diameter of 200 mm, an inside diameter of 125 mm and a length of 170 mm. Assume that the air gap in between armature and stator is chosen 0.3 mm. This means that the armature has an outside diameter of 124.4 mm.

It is chosen to use magnets of the company Enes with dimensions 80 * 20 * 10 mm. These magnets have a quality N35H and a remanence of about 1.19 T. The current price per magnet including VAT but excluding costs of transport is € 13.51 if at least 15 magnets are ordered. Sixteen magnets are use for one armature. So the total magnets costs are about € 220 which seems acceptable for this rather big PM-generator.

The original motor shaft is used. The mild steel armature has an outer diameter of 124.4 mm, an inner diameter of 50.1 mm and a length of 165 mm, so 5 mm shorter than the length of the stator stamping. The armature is pressed on the shaft such that at both sides, there is a distance of 2.5 mm with respect to the sides of the stator stamping. The armature is provided with eight grooves with a width of 20 mm and a depth of 10.9 mm. Two magnets are glued in each groove such that there is a distance of 5 mm in between both magnets. The north poles of all magnets are facing to the outside. This configuration makes that a total magnet length of 160 mm for two magnets matches best with a stator length of 170 mm.

At each side of a magnet groove there is a 4 mm wide and 7 mm deep groove to make that the south poles also have a width of about 20 mm and that there is no magnetic short-circuit in between the sides of the magnets.

The shaft has a diameter of 40 mm at the bearings and a shaft end with a diameter of 38 mm, a length of 80 mm and a 10 mm wide key groove. This shaft is strong enough for a windmill rotor with a diameter of about 4 m if the windmill is provided with a proper safety system. The back bearing cover can be closed. Selection of the windmill rotor is out of the scope of this report. It can best be done if a prototype of the generator has been built and tested on a test rig for the original 230/400 V winding and for different constant DC voltages for star and for delta rectification.

7 Ideas about a bigger 24-pole PM-generator using a 6-pole motor frame size 180L

Instead of using a 4-pole motor frame size 132M, it seems also possible to use a 6-pole motor frame size 180L. A 6-pole motor frame size 180L has a nominal motor power of 15 kW. The stator stamping of Kienle-Spiess has an inside diameter of 180 mm and a length of 240 mm. This gives an armature volume which is a factor 2.927 larger than that of the 4-pole motor as described in chapter 6. This means that a much larger windmill rotor can be used, also because the shaft diameter at the bearings is 50 mm instead of 40 mm for frame size 132M.

The stator stamping has 54 slots and so 54 stator poles. So the number of stator poles is a factor 1.5 larger than that of the 4-pole motor as described in chapter 6. This means that if the number of armature poles is also increased by a factor 1.5, so from 16 to 24, one still has a ratio in between the number of armature poles and the number of stator poles of 4 : 9. The number of preference positions per revolution is increased by a factor 1.5 and becomes 216.

The armature will get a length of 240 mm. Twelve 20 mm wide armature grooves are milled in the armature. It is assumed that the same magnets are used as for the 4-pole motor as described in chapter 6. Three magnets size 80 * 20 * 10 mm are used per groove. So the totally 36 magnets are needed and the total magnet costs are about € 495 which seems acceptable for this very big PM-generator.

The air gap is chosen 0.4 mm and so the armature diameter must be 179.2 mm. The armature can be made from 180 mm massive bar pressed to the original shaft. It seems also possible to make a 240 mm long bush from seamless steel pipe size 193.7 * 149 and to turn the original short-circuit armature to a diameter of 148.8 mm. The bush is glued to the short-circuit armature by anaerobe glue and turned to an outside diameter of 179.2 mm afterwards. The armature pitch is π * 179.2 / 24 = 23.5 mm. So 3.5 mm wide and 7 mm deep grooves have to be made at each side of the magnet grooves to make that the south poles also have a width of about 20 mm.

8 References

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