

**Ideas about a 30-pole, 3-phase permanent magnet generator using  
the housing and winding of a 6-pole asynchronous motor frame size 112M**

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April 2023

KD 747

It is allowed to copy this report for private use and to use the principles of the described PM-generator. The generator has not yet been built and tested.

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Contains	page
1 Introduction	3
2 Description of the 30-pole PM-generator	4
2.1 General	4
2.2 Description of the armature	4
2.3 Description of the stator	6
3 Determination of the flux density in the air gap	8
4 Checking if the standard winding can be used	9
5 Using a 40 mm long stator stamping for a smaller generator	10
6 Using a real 30-pole armature and a 3-phase, 1-layer winding	10
7 References	12

## 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 cogging 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 cogging torque if the armature isn't designed properly. A large peak on the cogging 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 cogging torque. I way to realise this for a generator made from a 4-pole asynchronous motor frame size 112M with 36 stator slots and using a 16-pole armature with magnets size 40 \* 15 \* 5 mm, is described in report KD 718 (ref. 2). In this report KD 747 it is researched if a housing of a 6-pole motor frame size 112M can be used in combination with a 30-pole armature. The advantage of using a 6-pole stator stamping is that it has a larger inside diameter of 115 mm instead of 103 mm for a 4-pole stator stamping of the same frame size. This results in an armature volume which is a factor  $(115/103)^2 = 1.25$  larger for the same armature length. As the maximum torque level is proportional to the armature volume, it will be also about a factor 1.25 larger. An advantage of using a 30-pole armature instead of a 16-pole armature is that the number of preference positions per revolution is higher (180 instead of 144). A disadvantage of using the standard 230/400 V, 3-phase winding of a 6-pole motor is that the generated voltage is about a factor 1.5 higher than for the standard 230/400 V, 3-phase winding of a 4-pole motor. So the generated voltage of the standard winding might be too high for 24 V or 48 V battery charging. But if this might be the case, the standard winding can be modified.

A starting point for this generator is that it can be made from the housing of a standard 6-pole asynchronous motor frame size 112M. 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 112 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 30-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](http://www.kienle-spiess.de). The chosen stator stamping has the code: IEC 112/6-8.1133. The outside diameter is 170 mm, the inside diameter is 115 mm. This stamping is used for a 2.2 kW, 6-pole motor and the length of the stator stamping is 140 mm for this motor. The stamping has 36 slots, so in between these slots there are 36 stator poles. The stamping has six 4.05 mm holes at a pitch circle of 164 mm. The manufacturer which uses this stamping of Kienle & Spiess for its 2.2 kW motor has not yet been selected.

It is chosen to use this stamping for an armature with six magnetic poles. A 6-pole armature has normally three north and three south poles. The angle in between the heart of a north pole and the heart of a south pole is  $60^\circ$  for a 6-pole generator. This means that the optimum angle in between two legs of a stator coil is  $60^\circ$  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 two coils which are lying within each other and for which the inner coil has an angle of  $50^\circ$  and for which the outer coil has an angle of  $70^\circ$ .

If the armature pole angle is chosen  $60^\circ$ , 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 115 mm diameter and 140 mm long steel bush which is pressed on the original motor shaft. The bush is turned to a diameter of 114.4 mm after pressing. Instead of using a massive steel bush, it might also be possible to use a seamless steel pipe size 115 \* 12.5 mm. This pipe has an inner diameter of 90 mm. The original short-circuit armature is turned to a diameter of about 89.8 mm and the pipe is glued to the armature with epoxy or anaerobe glue. The pipe is then turned to a diameter of 114.4 mm. It is chosen that the armature will get thirty mechanical poles and so five mechanical poles for one magnetic pole. Magnets are only used for the north poles. The south poles are formed by the remaining material of the armature.

It is chosen to use neodymium magnets size 40 \* 10 \* 4 mm. The magnets are supplied by the Polish company Enes Magnets website: [www.enesmagnets.pl](http://www.enesmagnets.pl). The magnets of this company are rather cheap if compared to magnets with the same volume of other magnet suppliers. The magnet size 40 \* 10 \* 4 mm has quality N38. The price for one magnet is € 1.55 including VAT (April 2023) excluding transport if at least 300 magnets are ordered.

Five 10 mm wide and 4.3 mm deep grooves are made for the magnets of one magnetic north pole. This can be done with a short and stiff 10 mm diameter cutter. The angle in between the heart of the grooves is  $12^\circ$ . The length of the armature is taken the same as the length of the stator, so 140 mm. As the length of a magnet is 40 mm, it means that 3 ½ magnets are glued in each groove. There are totally fifteen grooves, so eight magnets have to be broken in two 20 mm long pieces. This can be done if a deep scratch is made in the middle of the magnet.

The half magnets have to be mounted such that the broken side isn't facing to the outside of the armature. So this side is covered with glue and this prevents corrosion. So totally  $15 * 3 \frac{1}{2} = 52.5$  magnets are needed for one armature resulting in total magnet costs of about € 82 which is very low for a PM-generator of this size. Instead of a broken magnet size  $20 * 10 * 4$  mm, it is also possible to use two standard magnets size  $10 * 10 * 4$  mm. The magnets are glued in the grooves by epoxy or anaerobe glue.

The five mechanical south poles of one magnetic south pole are separated by grooves which make that the south poles also have a width of 10 mm. The angle in between the thirty poles is  $12^\circ$  and this means that there is  $2^\circ$  difference in between the armature pole pitch and the stator pole pitch. This means that there is a preference position every  $2^\circ$  and so there are  $360 / 2 = 180$  preference positions per revolution. I think that this is large enough to flatten the peak on the cogging torque sufficiently.

So the armature has totally thirty mechanical poles in the following sequence: N1, N2, N3, N4, N5, S1, S2, S3, S4, S5, N6, N7, N8, N9, N10, S6, S7, S8, S9, S10, N11, N12, N13, N14, N15, S11, S12, S13, S14 and S15. The north poles are formed by the magnets and therefore these are called the magnet poles. The south poles are formed by the steel armature bush and therefore these are called the iron poles.

In between two magnet grooves there is a 2 mm high rim. In between two south poles there is a 2 mm deep and 2 mm wide groove to make that the south poles also have a width of about 10 mm at the outside. These grooves can be made with a circular saw for steel. For manufacture it seems easy to start with thirty, 2 mm deep and 2 mm wide grooves at an angle of  $12^\circ$  and to make the fifteen 10 mm wide and 4.3 mm deep grooves afterwards.

The stator has 36 slots so it has 36 poles and so the stator pole angle is  $10^\circ$ . 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, 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 grooves in the stator stamping make that the armature may get thirty 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. The six 4.05 mm holes at a pitch circle of 164 mm in the stamping of Kienle and Spiess may also cause thirty 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 140 mm in each hole.

The armature is made of a 140 mm long mild steel bush with an outer diameter of 115 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 38 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 38 mm, so for instance 38.1 mm, otherwise the required pressing force may be too high. The armature is turned to a diameter of 114.4 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  $(115 - 114.4) / 2 = 0.3$  mm.

The 10 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 52.9 mm. This means that the depth of the groove measured from the outside of the armature is  $57.2 - 52.9 = 4.3$  mm. The magnets are not jutting out of the armature for this groove depth. The average air gap at the magnets of the north poles is somewhat larger than the air gap at the iron south 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.

An extra advantage of using the housing of a 6-pole motor, is that now the armature has three bundles of each five south poles under an angle of  $120^\circ$ . This prevents scratching of the magnetic north poles when the armature is mounted in the stator. The armature is only centred after tightening of the bearing covers.

### 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 two coils of one phase are positioned as a bundle within each other.

The winding is a so called 3-layers winding. This means that the three bundles of two coils of phase U are laid in the first layer. The three bundles of two coils of phase V are laid in the second layer. The three bundles of two coils of phase W are laid in the third layer. The coil heads of the coils in the first and the second layer are bent to the outside to make place for the coils of the third layer.

The two coils of a coil bundle are always connected in series because the voltage generated in each of the coils isn't exactly the same. The three coil bundles of a layer are normally connected in series for a standard 230 / 400 V winding. However, these three coil bundles can be connected in parallel which results in decrease of the voltage by a factor 3 and in increase of the current by a factor 3.

The six coils of one phase are made outside the generator. Each layer with six coils has an end labelled A and an end labelled B. The both ends A and B 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 B 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  $\sqrt{3}$ . A disadvantage of delta connection is that higher harmonic currents can circulate in the winding and this results in a stronger increase of the unloaded torque than for star connection. An advantage of delta connection is that the maximum torque for short-circuit is higher. Short-circuit in star is the same as short-circuit in delta if the star point is short-circuited too.

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

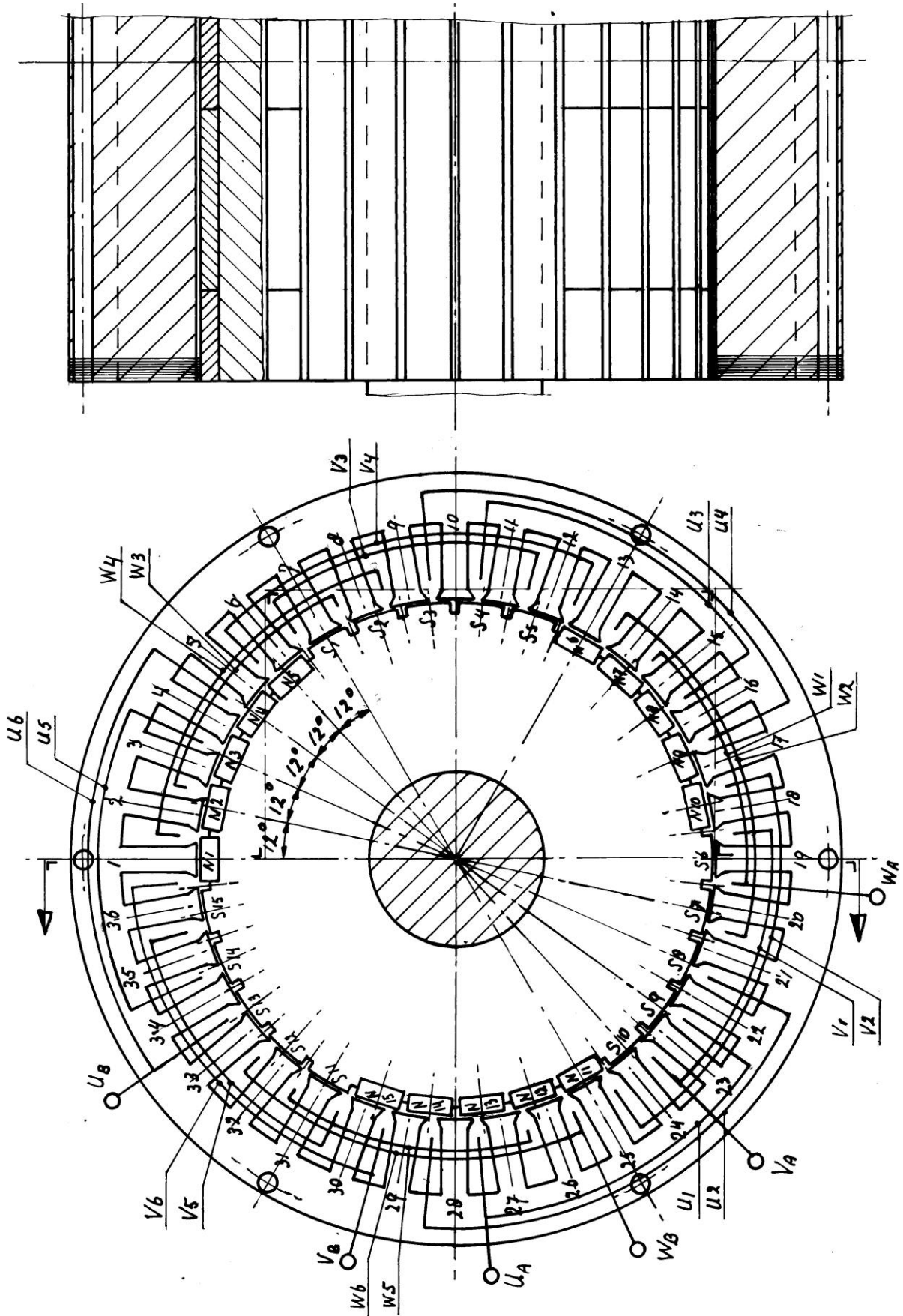


fig. 1 30-pole, 3-phase PM-generator with a 6-pole, 3-layers, 230/400 V, 3-phase winding

### 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. Six magnetic loops are coming out of a normal 6-pole armature. Three loops are turning left hand and three loops are turning right hand. However, eighteen magnetic loops are coming out of this special 30-pole armature. Nine loops are turning left hand and nine loops are turning right hand. There are six bundles of each three loops. The two inner loops of a bundle are coming out of a whole magnetic north pole. The central magnet of five north poles supplies two smaller loops of which one is turning left hand and one is turning right hand.

A magnet has a thickness  $t_1 = 4$  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 115 mm. It is assumed that the armature is turned at a diameter of 114.4 mm at the south poles. So the air gap at the south 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 4.3 mm which means that the air gap at the heart of the 4 mm thick magnet is 0.6 mm. The air gap at the sides of the magnet is about 0.4 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  $t_3 = 0.55$  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:

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

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 if the iron in the stator isn't saturated. The used magnets with quality N38 have a remanence  $B_r$  of about 1.24 T. Substitution of  $B_r = 1.24$  T,  $t_1 = 4$  mm,  $t_2 = 0.3$  mm and  $t_3 = 0.55$  mm in formula 1 gives that  $B_{r\text{eff}} = 1.02$  T.

In figure 1 it can be seen that there is a position of the armature for which one armature pole is opposite to one stator pole. A stator pole is formed by the spokes left in between the stator slots. These stator slots have a tapered shape and the spokes therefore have a constant width of about 5.6 mm except for the most inner part for which the width is about 7.5 mm. The armature poles have a width of 10 mm. So the magnetic flow is concentrated in the spokes by a factor  $10 / 5.6 = 1.786$ . This means that the flux density in the spokes is  $1.786 * 1.02 = 1.82$  T. The stator iron is saturated at about 1.6 T. So the stator is strongly saturated at the spokes and formula 1 is therefore no longer valid. But this calculation shows that the chosen magnet configuration is rather optimal and that it is useless to use thicker magnets or to use also magnets for the south poles.

### 4 Checking if the standard winding can be used

The standard winding of a 6-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 30-pole generator. I will not perform measurements for this new generator.

First the generator is connected in star and the  $P_{\text{mech-n}}$  and  $P_{\text{el-n}}$  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  $P_{\text{mech-n}}$  and  $P_{\text{el-n}}$  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  $P_{\text{mech-n}}$  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  $P_{\text{mech-n}}$  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 2 but the  $P_{\text{mech-n}}$  curve, the  $P_{\text{el-n}}$  curve and the P-n curve for short-circuit in star and delta of the original VIRYA-3B3 generator are removed.

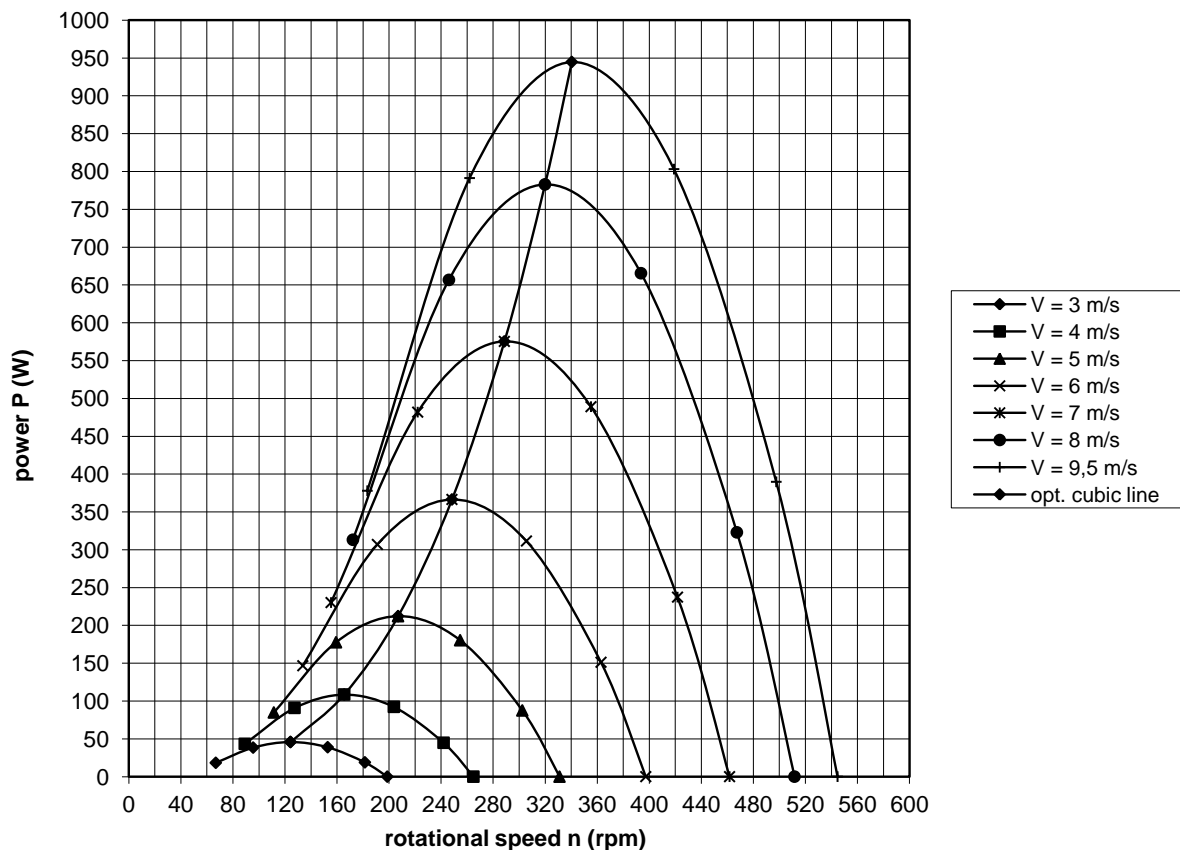


fig. 2 P-n curves of the VIRYA-3B3 rotor for  $V_{\text{rated}} = 9.5$  m/s and optimum cubic line

The original VIRYA-3B3 generator has a 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 112.

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 Using a 40 mm long stator stamping for a smaller generator**

The same magnet orientation can be used for a smaller generator if the stator stamping has a length of only 40 mm. In this case the stator length is 40 mm too and there is only one magnet size 40 \* 10 \* 4 mm per groove. So totally fifteen magnets are used and the total magnet costs are only about € 24 which is very low for a PM-generator of this size. It is assumed that a 40 mm long stator stamping is supplied by Kienle & Spiess if the ordered quantity is large enough. So this option is only realistic if the generator is mass produced. It may even be possible to order an armature stamping with the correct shape for mounting of the magnets which eliminates the manufacture of an armature from massive bar.

Now it is no longer possible to use the housing of a standard 6-pole motor but the pattern of the stator winding is similar. An option is to use two aluminium bearing covers which are pulled to the stator stamping by six threaded rods M4 at a pitch circle of 164 mm. The outside of the stator stamping must now be painted by epoxy paint to prevent rust. This generator can have a shaft with a diameter of 20 mm at the bearings and a tapered shaft end with a half cone angle of 5° for connection of the rotor hub. The back bearing cover is closed. One can also use a stator with a length of 80 mm and two magnets per groove and a 25 mm shaft. An advantage of a complete new generator is that the winding can now be optimised for a certain windmill rotor. Further description of this option is out of the scope of this report.

### **6 Using a real 30-pole armature and a 3-phase, 1-layer winding**

If a new stator winding is laid as proposed in chapter 5 for a small generator, at might also be an option to use a real 30-pole armature and a stator with a 3-phase, 1-layer winding. A real 3-pole armature means that now the armature has 15 north poles and 15 south poles. The 15 north poles are formed by 15 of the same magnets size 40 \* 10 \* 4 mm as used in figure 1. The 15 south poles are formed by the remaining material of the armature. At each side of a magnet there is a 2 mm wide and 3.3 mm deep groove to make that the south poles also have a width of 10 mm and the prevent a magnetic short-circuit in between the sides of the magnets. The north poles are numbered N1 – N15. The south poles are numbered S1 – S15.

The stator has 36 poles numbered 1 – 36. The stator has 18 coils and so six coils for each phase. The six coils of a phase are numbered 1 – 6. Each coil is wound around only one stator spoke and therefore the winding is a 1-layer winding with no crossing coils heads. Such a winding has as advantage that the coil heads are very small and therefore the minimum amount of copper is needed and the coil heads take only a little space in the bearing covers. It is assumed that coil U1 is wound around spoke 1. A side view of the armature is given in figure 2. The armature is drawn such that north pole N1 is opposed to coil U1.

In figure 2 it can be seen that if north pole N1 is opposed to coil U1, north pole N6 is opposed to coil U2 and north pole N11 is opposed to coil U3. The coils U1, U2 and U3 are connected in series and so the winding direction of these three coils must be the same. In figure 2 it can be seen that if north pole N1 is opposed to coil U1, south pole S3 is opposed to coil U4, south pole S8 is opposed to coil U5 and south pole S13 is opposed to coil U6. The coils U4, U5 and U6 are also connected in series and so the winding direction of these three coils must be opposite the winding direction of the coils U1, U2 and U3.

The bundle of the three coils U1, U2 and U3 has a beginning labelled A and an end labelled B. The bundle of the three coils U4, U5 and U6 has a beginning labelled C and an end labelled D. A bundle of three coils is wound outside the stator on a winding thorn. For manufacture, it is easy if all bundles of three coils have the same winding direction and if all coil bundles are laid in the stator in the same way. So to make that the voltages of all six coils are strengthening each other, end B has to be connected to end D and end C becomes the star point if both coil bundles are connected in series. The direction of the current in both coil bundles will then be different. If both coil bundles are connected in parallel, beginning A has to be connected to end D and end B has to be connected to beginning C.

This option of connecting the coil bundles in series or in parallel makes that the generator can be used for two different voltages which differ a factor 2. It is assumed that the winding is rectified in star. So generator can be used for charging of a 12 V battery if the coil bundles are connected in parallel and for 24 V battery charging is the coil bundles are connected in series. It is easiest to use a terminal block with nine terminals in three rows of three terminals and to guide the nine coil ends labelled A, B and D to this terminal block. The three coil ends  $U_C$ ,  $V_C$  and  $W_C$  are forming an internal star point. The coil ends  $U_B$ ,  $V_B$  and  $W_B$  are forming a second star point if the coil bundles are connected in parallel. This option is described in chapter 5 of report KD 580 (ref. 6).

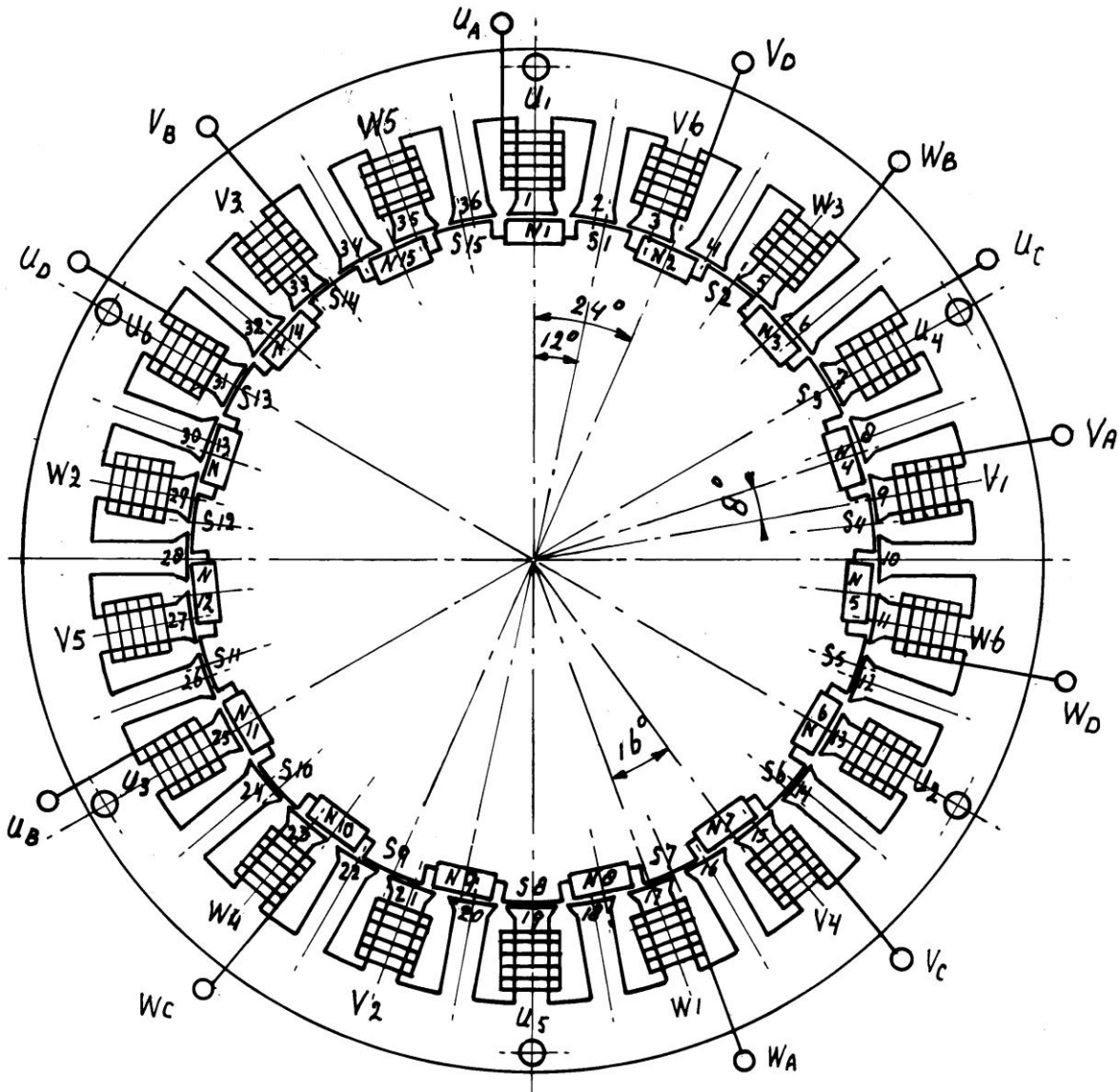


fig. 2 30-pole armature and 1-layer, 3-phase winding

In figure 2 it can be seen that the coil sequence is: U1, V6, W3, U4, V1, W6, U2, V4, W1, U5, V2, W4, U3, V5, W2, U6, V3 and W5. The wire ends A, B, C and D are drawn in figure 2. The wires which connect the three coils of a coil bundle are not drawn in figure 2.

A rotational angle  $\beta = 24^\circ$  corresponds to a phase angle  $\alpha = 360^\circ$ . In figure 2 it can be seen that the angle  $\beta$  in between V1 and N4 is  $8^\circ$  and so this correspond to a phase angle  $\alpha = 120^\circ$ . The angle  $\beta$  in between W1 and N7 is  $16^\circ$  and so this correspond to a phase angle  $\alpha = 240^\circ$ . So a 3-phase current is generated in between the coils U1, V1 and W1.

A real 30-pole armature has 30 magnetic loops coming out of the armature. The magnetic flux coming out of north pole N1 splits into a left hand loop going to the right half of south pole S15 and into a right hand loop going to the left half of south pole S1.

The stator stamping is originally used for a 6-pole motor and a strong magnetic field is flowing through the bridge in between the bottom of a slot and the outside of the stator. But for a 30-pole generator, this magnetic flux is much smaller because it is coming out of only one stator spoke. The stator stamping will therefore be saturated only at the spokes and never at the bridge in between the bottom of the slots and the outside of the stator.

The construction of the generator can be similar as the construction given in figure 1 of report KD 580 (ref. 6) for a 34-pole generator. So one can use a 40 mm long stator and two aluminium bearing covers which are pulled against the stator by six threaded rods M4. One can use a shaft with a diameter of 20 mm at the bearings and a tapered shaft end. One can also use a 80 mm long stator, 30 magnets and a 25 mm shaft at the bearings.

## 7 References

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