Ideas about a 16-pole, 28-pole, 32-pole or 40-pole, 3-phase permanent magnet generator using the housing and winding of a 4-pole asynchronous motor

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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 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 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 112 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 112. 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 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 112/4.103. The outside diameter is 170 mm, the inside diameter is 103 mm. This stamping is used for a 4 kW, 4-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 4.03 mm holes at a pitch circle of 164 mm. The manufacturer which uses this stamping of Kienle & Spiess for its 4 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 103 mm diameter and 140 mm long steel bush which is pressed on the original motor shaft. The bush is turned to a diameter of 102.4 mm after pressing. It is chosen that the armature will get sixteen mechanical poles and so four 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 * 15 * 5 mm. The 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 price for one magnet is € 1.44 including VAT (February 2024) excluding transport if at least 140 magnets are ordered.

Four 15 mm wide and 5.7 mm deep grooves are made for the magnets of one magnetic north pole. This can be done with a short and stiff 15 mm diameter cutter. The angle in between the heart of the grooves is 22.5°. 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 eight grooves, so four 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 8 * 3 ½ = 28 magnets are needed for one armature resulting in total magnet costs of about € 41 which is very low for a PM-generator of this size.

The four south poles are separated by grooves such that the south poles also have a width of 15 mm. If the angle in between all sixteen poles would be 22.5°, it means that there is 2.5° difference in between the armature pole pitch and two times the stator pole pitch. This means that there is a preference position every 2.5° and so there are 360 / 2.5 = 144 preference positions per revolution. I am not sure that this is large enough to flatten the peak on the cogging torque sufficiently. The number of preference positions can be doubled if the pattern of the group of four south poles is rotated 1.25° left or right hand with respect to the pattern of the group of four north poles. The peak on the cogging torque caused by the north poles will then not coincide with the peak on the cogging torque caused by the south poles.

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 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 3 mm deep and 5 mm wide groove to make that the south poles also have a width of about 15 mm at the outside.

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, 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. The six 4.03 mm holes at a pitch circle of 164 mm in the stamping IEC 112/4.103 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 140 mm in each hole.

The armature is made of a 140 mm long mild steel bush with an outer diameter of 103 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 102.4 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 (103 – 102.4) / 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 45.5 mm. This means that the depth of the groove measured from the outside of the armature is 51.2 – 45.5 = 5.7 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.

A disadvantage of using four magnetic north poles and four iron south poles is that some magnets of the north poles may get scratches when the armature is mounted in the stator. The armature is only centred after tightening of the bearing covers. This problem can be solved by painting of the magnets with epoxy or by making an epoxy or plastic rim with R = 51.2 mm in between the magnets N2 and N3 and in between the magnets N6 and N7.

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 √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).

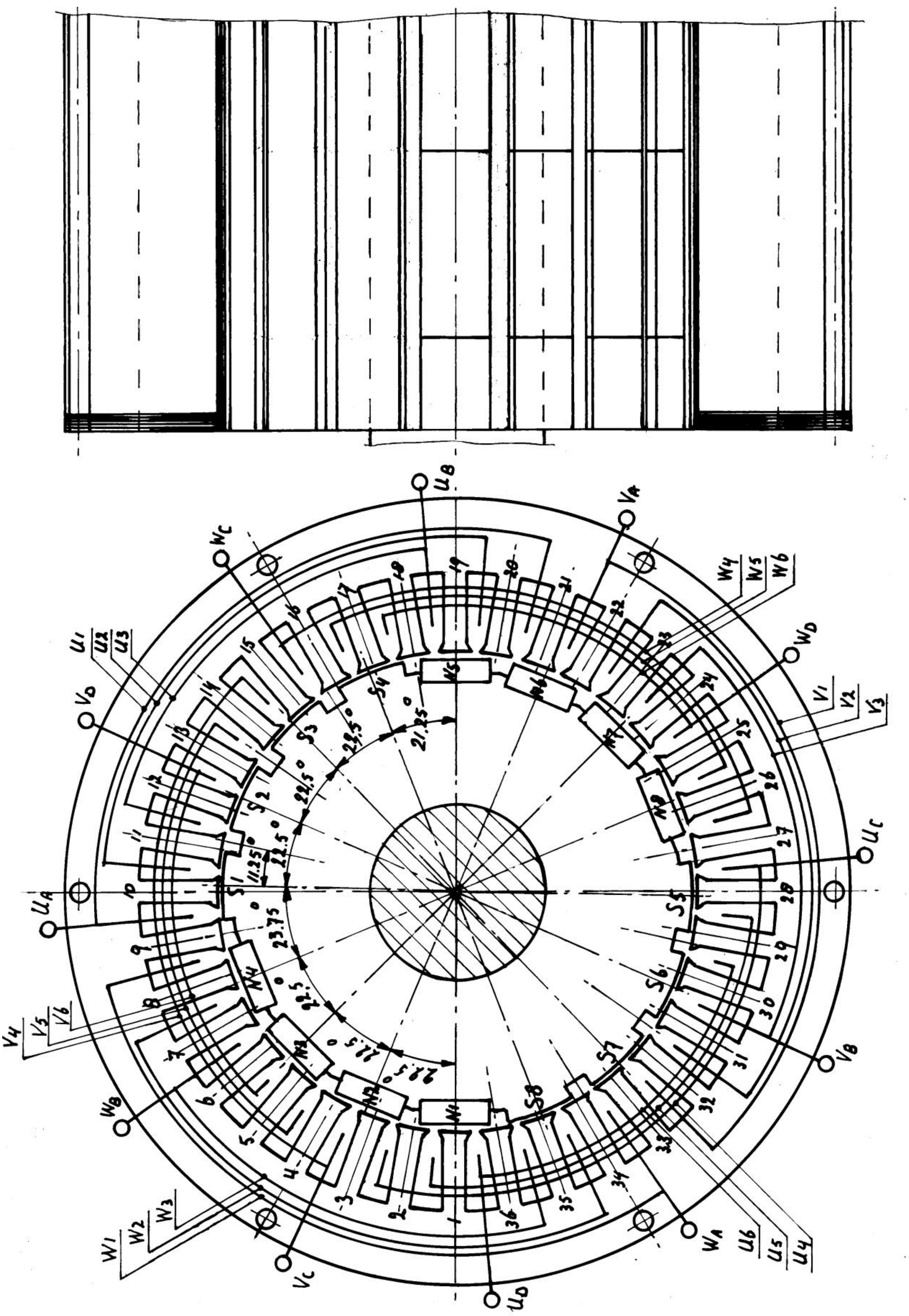


fig. 1 16-pole, 3-phase PM-generator with a 4-pole, 2-layers, 230/400 V, 3-phase winding

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. 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 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 the magnet of north pole N2 flows through the large air gap t_3 into the stator stamping. Next it makes a left hand bend. Next it flows through the small air gap t_2 and enters the south pole S7. Next it flows into the steel armature bush, making a left hand bend 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 103 mm. It is assumed that the armature is turned at a diameter of 102.4 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 such that there is a distance of 45.5 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 51.5 – (45.5 + 5) = 1 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 = 0.8 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:

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

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 = 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 figure 1 it can be seen that one armature pole is about opposite to two stator poles. 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 mm except for the most inner part for which the width is about 7 mm. The armature poles have a width of 15 mm. So the magnetic flow is concentrated in the spokes by a factor 15 / (2 * 5) = 1.5. This means that the flux density in the spokes is 1.5 * 1.02 = 1.53 T. The stator iron is saturated at about 1.6 T. So the stator is just not saturated at the spokes but close to saturation and formula 1 is therefore valid. This calculation shows that the chosen magnet configuration is rather optimal and that it is useless to use thicker magnets.

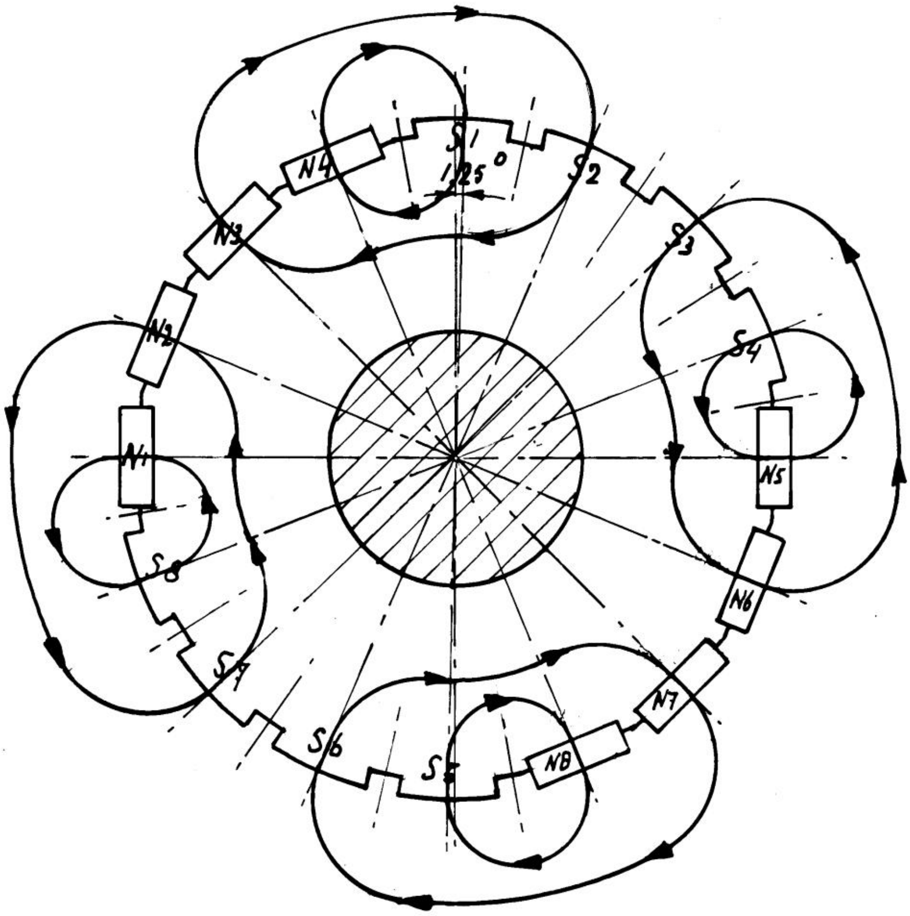


fig. 2 16-pole armature with four left hand and four right hand magnetic loops

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.

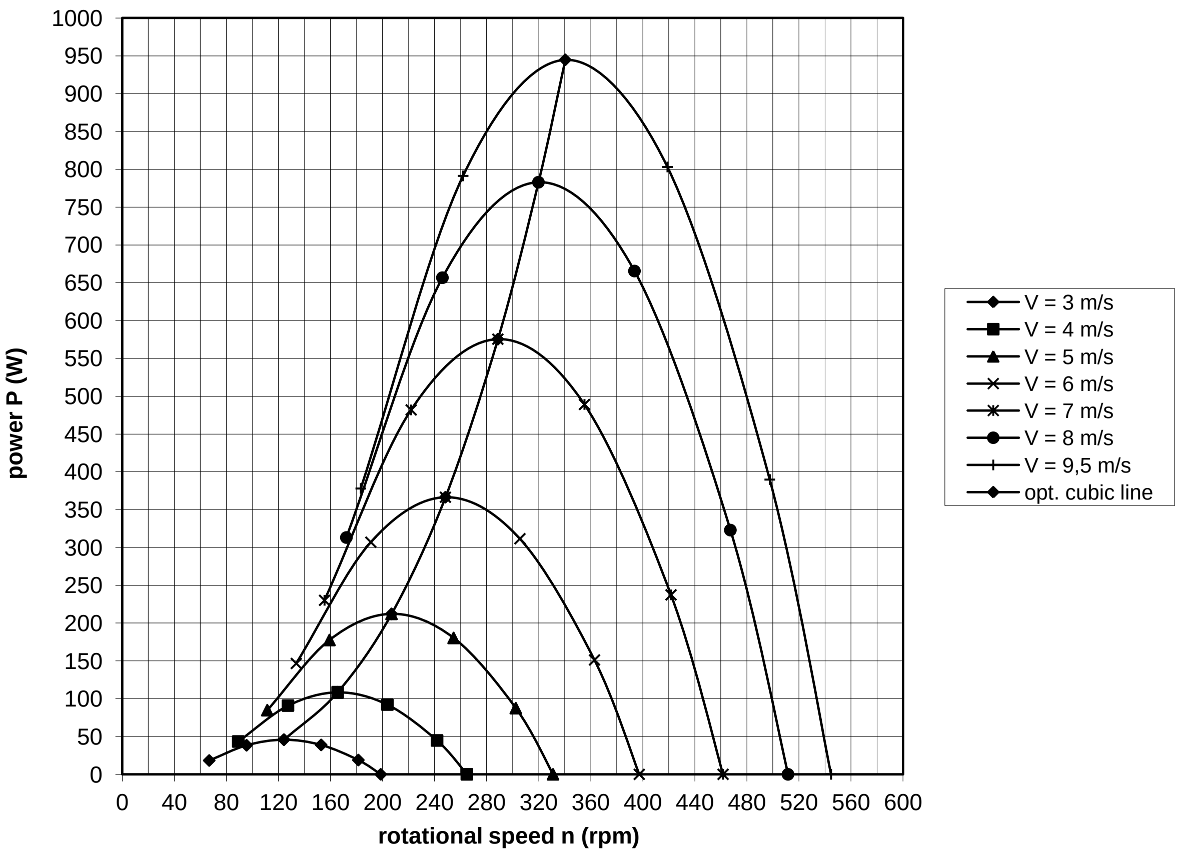


fig. 3 P-n curves of the VIRYA-3B3 rotor for V_{rated} = 9.5 m/s and optimum cubic line

The original VIRYA-3B3 generator has a frame size 90 and a 25 mm tapered shaft. So the rotor 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 disadvantage of delta rectification is that the cogging 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:

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

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:

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

(2) + (3) gives:

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

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 45.5 mm from the armature axis. So the centre of gravity of a magnet lies at 45.5 + 2.5 = 48 mm from the axis of the armature. This gives that r = 0.048 m. Substitution of m = 0.0225 kg, r = 0.048 m and n = 600 rpm in formula 4 gives that F_c = 4.3 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 4.3 / 600 = 0.0072 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 1389 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 Use of a 4-pole motor frame size 100L and a 32-pole armature

A way to increase the number of preference positions per revolution is to increase the number of mechanical armature poles from 16 to 32. However, this requires smaller magnets. It is chosen to use magnets size 40 * 7 * 3 mm which are also supplied by Enes magnets. These magnets have quality N38SH. The current price (February 2024) is € 0.55 per piece including VAT but excluding costs of transport if 180 pieces are ordered.

It is chosen to use a 4-pole, 3 kW asynchronous motor frame size 100L with a stator stamping if Kienle & Spiess code IEC 100/4.944. This stator stamping has an outside diameter of 150 mm, an inside diameter of 90 mm and a length of 120 mm. The outside diameter of the armature is 89.5 mm and so the air gap at the south poles is 0.25 mm. Magnets are only used for the north poles. Every magnetic pole has eight mechanical poles.

The grooves for the north poles have a width of 7 mm and a depth of 3.2 mm. An advantage of 7 mm wide magnets is that the air gap at the north poles is much smaller than for 15 mm wide magnets. There is a 1 mm high rim which separates the grooves of the north poles. To make that the south poles also have a width of about 7 mm, a 1.8 mm wide and 2.2 mm deep groove is made to separate the south poles. To make the 1 mm high rim which separates the north poles, it is easy to make first 32, 1.8 mm wide and 2.2 mm grooves every 11.25° and to make the 7 mm wide magnet grooves afterwards. Three magnets are glued in each groove and so totally 3 * 8 * 2 = 48 magnets are needed for one armature. The total magnet costs are about € 27 which is rather low for a PM-generator of this size. A side view this armature is given in figure 4.

The armature pole angle is 360 / 32 = 11.25°. The stator pole angle is 360 / 36 = 10°. So the difference is 1.25°. Assume that there is a preference position if an armature pole is just opposite a stator pole. This is the case for 4 of the 32 armature poles. This changes every 1.25° and so the armature will have 360 / 1.25 = 288 preference positions per revolution. The peak on the cogging torque will be very low for that many preference positions and the starting wind speed will therefore be rather low. It is expected that this generator can be used in combination with the VIRYA-3B3 rotor (see chapter 4).

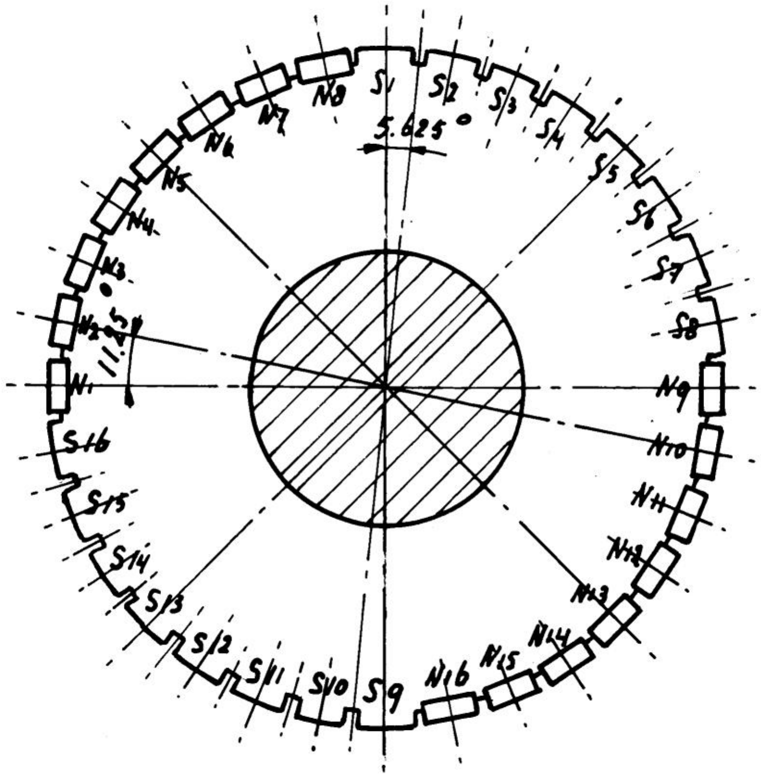


fig. 4 Side view 32-pole armature with 48 magnets size 40 * 7 * 3 mm

The shaft end dimensions of a motor frame size 100L are the same as that of a motor frame size 112M. The shaft diameter at the bearings is 30 mm. But the shaft diameter at the armature stamping is 36 mm instead of 38 mm. The shaft end has a diameter of 28 mm, a length of 60 mm and an 8 mm wide key groove. So the rotor hub has to be modified for a 28 mm cylindrical shaft and the generator bracket has to be modified for a generator frame size 100 instead of 90. The original VIRYA-3B3 generator has a generator made from a motor frame size 90 with lengthened stator stamping and a shaft diameter of 25 mm with a tapered shaft end with a half taper angle of 5°. So a 28 mm shaft end will be strong enough.

The armature of the original generator has a diameter of 82.02 mm. The armature has a length of 135 mm but the length of the armature within the stator stamping is 125 mm. So the armature volume within the stator stamping is 660449 mm^3. The armature makes use of eight neodymium magnets size 67 * 20 * 10 mm. So the total magnet volume is 107200 mm^3.

The armature of a generator made from a motor frame size 100L has a diameter of 89.5 mm and a length of 120 mm. So the armature volume is 754948 mm^3. This is a factor 1.143 larger. The armature makes use of 48 neodymium magnets size 40 * 7 * 3 mm. So the total magnet volume is 40320 mm^3. This is only a factor 0.376 of the magnet volume of the original generator and the magnet costs are therefore much lower. It is calculated that even with 3 mm thick magnets, the stator spokes are saturated. So even with much thinner magnets, the torque level will be high enough for the VIRYA-3B3 rotor. But it is good to build a prototype and to measure it on a test rig to verify if the characteristics are acceptable and if they are about the same as for the original generator as given in report KD 78 (ref. 6).

7 Use of a 4-pole motor frame size 132M and a 32-pole armature

It seems possible to use the same principle of a 32-pole armature as explained in chapter 6, for a bigger motor frame size 132 if magnets size 40 * 10 * 5 mm are used. The stator stamping of a 7.5 kW, 4-pole motor of Kienle & Spiess has an outside diameter of 200 mm, an inside diameter of 125 mm and a length of 170 mm. It is assumed that the armature gets an outside diameter of 124.4 mm and a length of 170 mm.

Four magnets are glued in one groove and so the available groove length for one magnet is 42.5 mm. The magnets must be glued such that there is a distance of 2.5 mm in between the magnets and a distance of 1.25 mm in between the side of the armature and the side of a magnet. The air gap at the south poles is 0.3 mm. The magnet grooves get a depth of 5.3 mm and so the air gap at the heart of a magnet is 0.6 mm. The average air gap at the north poles is about 0.5 mm. It is expected that the stator iron is close to saturation for these magnets.

It is assumed that the original motor has a 230/400 V, 4-pole, 3-phase winding and that this original winding can be used for 24 battery charging if the winding is rectified in delta and for 48 V battery charging if the winding is rectified in star. But to be sure that there is an acceptable matching for the chosen windmill rotor (which might be the VIRYA-4.2 rotor), a prototype of the generator has to be measured on an accurate test rig.

The eight grooves for the north poles have a width of 10.1 mm and a depth of 5.3 mm. This depth makes that the magnets don’t jut outside the armature. The south poles are separated by 2.2 mm wide and 3 mm deep grooves to make that the south poles also have a width of about 10 mm.

Magnets size 40 * 10 * 5 are also supplied by Enes Magnets. The price including VAT but excluding costs of transport is € 1.08 (February 2024) if 150 magnets are ordered. 4 magnets are used in one groove and so the total number of magnets needed is 16 * 4 = 64. So the total magnet costs for one armature are about € 70 which seems acceptable for such a big PM-generator. The front end of the original motor shaft has a diameter of 38 mm, a length of 80 mm and a 10 mm wide key groove. It is expected that this generator can be used for the 3-bladed VIRYA-4.2B3 windmill as an alternative for the Chinese generator type TGET380-10KW-1200R. The VIRYA-4.2B3 is described in report KD 769 (ref. 7).

8 Use of a 4-pole motor frame size 80 and a 28-pole armature

It seems possible to use the same principle as described in chapter 6, for a smaller 4-pole motor frame size 80. However, such a motor has a stator stamping with 24 poles instead of 36 poles. So there are six instead of nine stator poles opposed to one magnetic armature pole. Now it is chosen to take seven mechanical north poles for one magnetic north pole. The same magnets size 40 * 7 * 3 mm are used for the north poles as used for the 32-pole generator.

The stator pole angle is 360 / 24 = 15°. The armature pole angle is 360 / 28 = 12.857°. So the difference is 15° - 12.857° = 2.143°. This means that the armature will have 360 / 2.143 = 168 preference positions per revolution. This is less than the 288 preference positions of the 32-pole generator but I expect that the peak on the cogging torque will be low enough to get a sufficiently low starting wind speed if a windmill rotor with a rather high starting torque coefficient is chosen.

It is chosen to use a 4-pole, 0.75 kW asynchronous motor frame size 80 with a stator stamping if Kienle & Spiess code IEC 80/4.70. This stator stamping has an outside diameter of 120 mm, an inside diameter of 70 mm and a length of 80 mm. The outside diameter of the armature is 69.5 mm and so the air gap at the south poles is 0.25 mm. The armature stamping has an inside diameter of 25 mm. The original short-circuit armature is removed and replaced by a mild steel bush with a diameter of 70 mm and a length of 80 mm. This bush is turned to a diameter of 69.5 mm after pressing it onto the original motor shaft.

It might also be possible to use an 80 mm long seamless steel pipe size 70 * 6 mm. This pipe has an inside diameter of 58 mm. The original short-circuit armature is turned to a diameter of 57.8 mm and the bush is glued to the original armature using epoxy glue or anaerobe glue. Magnets are only used for the north poles. Every magnetic pole has seven mechanical poles. The grooves for the north poles have a width of 7 mm and a depth of 3.3 mm. For this groove depth, it appears that the magnets don’t jut out of the armature. The armature pole pitch is π * 69.5 / 28 = 7.8 mm which is rather small for 7 mm wide magnets. It is calculated that the distance in between the magnets at the bottom of the magnet grooves is only about 0.1 mm.

So there is no space for a rim in between the magnets. It seems easiest to glue first the three left magnets, then the three right magnets and to finish with the central magnet.

The south poles are formed by the remaining material of the armature. To make that the south poles have a width of about 6.8 mm, a 1 mm wide and 2 mm deep groove is made to separate the south poles. To prevent that there is a 0.1 mm wide rim in between the grooves of the north poles, it is easy to make first six, 1 mm wide and 3.1 mm deep grooves in between seven north poles. The seven 7 mm wide and 3.3 mm deep magnet grooves are made afterwards.

Two magnets are glued in each groove and so totally 2 * 7 * 2 = 28 magnets are needed for one armature. The total magnet costs are about € 16 which is rather low for a PM-generator of this size. A side view this armature is given in figure 5.

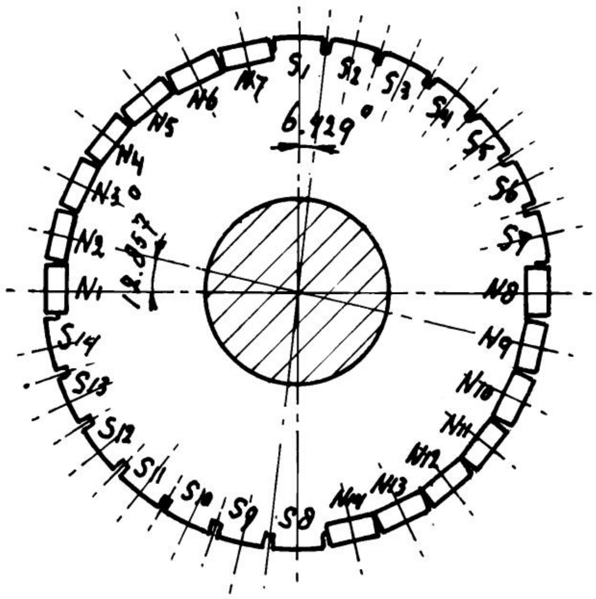


fig. 5 Side view 28-pole armature with 28 magnets size 40 * 7 * 3 mm

A motor frame size 80 has a shaft with a diameter of 20 mm at the bearings. The cylindrical shaft end has a diameter of 19 mm, a length of 40 mm and a 6 mm wide key groove. No fan is used and the bearing cover at the original fan side is closed. It is expected that this generator can be used in combination with a windmill rotor with a diameter of maximal 2 m.

It is good to build a prototype and to measure the characteristics for the original 230/400 V winding but I won’t do that. One should measure the P_{mech}-n and P_{el}-n curves for a 24 V and a 48 V battery if the winding is rectified in star and for a 12 V and a 24 V battery if the winding is rectified in delta. The peak on the cogging torque at stand still position has to be measured too. The diameter and design tip speed ratio of the windmill rotor should be chosen such that there is good matching in between rotor and generator with one of the measured P_{mech}-n curves. Matching is explained in chapter 8 of report KD 35 (ref. 4).

9 Use of a 4-pole motor frame size 160L and a 40-pole armature

It seems possible to use the same principle as described in chapter 7, for a bigger 4-pole motor frame size 160L. Such a motor has a stator stamping with 36 poles. So there are nine stator poles opposed to one magnetic armature pole. Now it is chosen to take ten mechanical north poles for one magnetic north pole. Magnets size 40 * 10 * 5 mm are used for the north poles. The stator pole angle is 360 / 36 = 10°. The armature pole angle is 360 / 40 = 9°. So the difference is 10° - 9° = 1°. This means that the armature will have 360 / 1 = 360 preference positions per revolution. This is more than the 288 preference positions of the 32-pole generator and the peak on the cogging torque will therefore be very low.

It is chosen to use a 4-pole, 15 kW asynchronous motor frame size 160L with a stator stamping if Kienle & Spiess code IEC 160/4.150. This stator stamping has an outside diameter of 240 mm, an inside diameter of 150 mm and a length of 215 mm. The outside diameter of the armature is chosen 149.2 mm and so the air gap at the south poles is 0.4 mm. The armature stamping has an inside diameter of 55 mm. The original short-circuit armature is removed and replaced by a mild steel bush with a diameter of 150 mm and a length of 215 mm. This bush is turned to a diameter of 149.2 mm after pressing it onto the original motor shaft.

It might also be possible to use a 215 mm long seamless steel pipe size 150 * 10 mm. This pipe has an inside diameter of 130 mm. The original short-circuit armature is turned to a diameter of 129.8 mm and the bush is glued to the original armature using epoxy glue or anaerobe glue.

Magnets are only used for the north poles. Every magnetic pole has ten mechanical poles. The grooves for the north poles have a width of 10 mm and a depth of 4.3 mm. For this groove depth, it appears that the magnets don’t jut out of the armature. There is a 1 mm high rim in between adjacent north poles.

The south poles are formed by the remaining material of the armature. To make that the south poles also have a width of about 10 mm, a 1.7 mm wide and 4.3 mm deep groove is made to separate the south poles. To make the 1 mm high rim in between the north poles, it is easy to make first 40, 1.7 mm wide and 3.3 mm deep grooves at an angle of 9°. The ten 10.1 mm wide and 5.3 mm deep magnet grooves are made afterwards.

Five magnets are glued in each groove and so totally 2 * 10 * 5 = 100 magnets are needed for one armature. The armature has a length of 215 mm which is 15 mm longer than the total length of five magnets. So the outer magnets are positioned 1.5 mm from the side of the armature and there is a distance of 3 mm in between the magnets. So 40 mm magnet length covers 43 mm armature length.

The magnets are also supplied by Enes magnets. The current magnet price is € 1.08 (February 2024) a piece including VAT and excluding costs of transport if at least 150 magnets are ordered. So the total magnet costs are about € 108 which is rather low for a PM-generator of this size. A picture of this armature is given in figure 6.

A motor frame size 160L has a shaft with a diameter of 45 mm at the bearings. The cylindrical shaft end has a diameter of 42 mm, a length of 110 mm and a 12 mm wide key groove. No fan is used and the bearing cover at the original fan side is closed. It is expected that this generator can be used in combination with the rotor of the VIRYA-5B3 windmill. This rotor is described in report KD 710 (ref. 8). The VIRYA-5B3 out of KD 710 is meant to be coupled to an axial flux generator of Hefei Top Grand. The 40-pole generator is an alternative for this axial flux generator but this requires modification of the hub plate and the hub of the rotor and modification of the generator bracket.

It is good to build a prototype and to measure the characteristics for the original 400/690 V winding but I won’t do that. One should measure the P_{mech}-n and P_{el}-n curves for a range of resistance loads. The peak on the cogging torque at stand still position has to be measured too.

The generator will be grid connected using a 3-phase inverter. Selection of the correct inverter is out of the scope of this report. It is assumed that the voltage of the inverter can be adjusted such that the optimum cubic line of the rotor is followed.

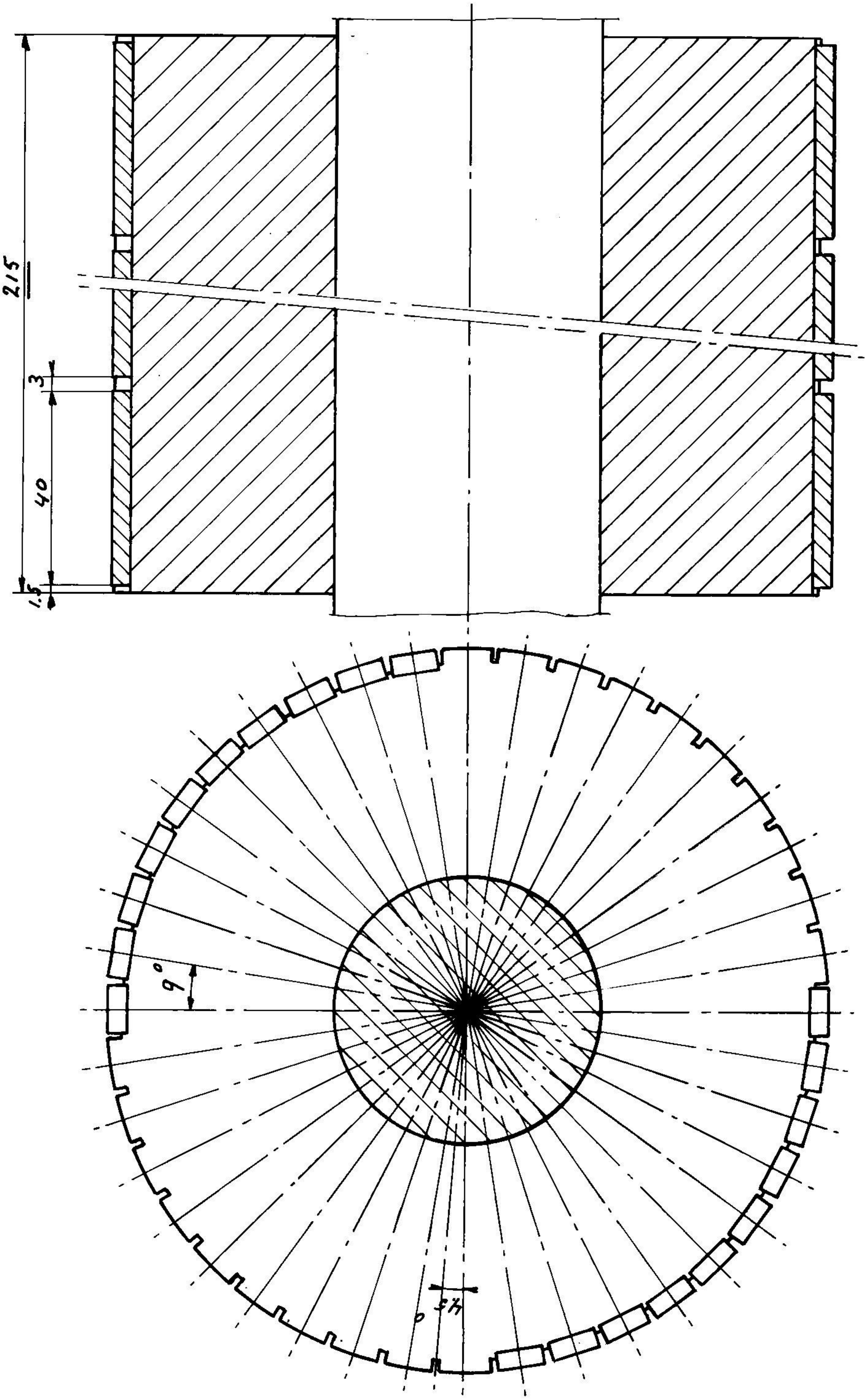


fig. 6 40-pole armature with 100 magnets size 40 * 10 * 5 mm

10 Use of a 4-pole motor frame size 112 and a 28-pole original armature

The disadvantage of all previous options is that the original short-circuit armature can't be used because it has aluminium short-circuit bars at the wrong positions. So a new armature has to be made. It might be possible to use the original armature for a special magnet configuration. The used armature and stator stamping are of manufacture Kienle & Spiess. Recently the name of this company has been changed into Feintool. Information about the geometry of armature and stator stampings of asynchronous motors is found by following the path: www.feintool.com – Online catalogue industry – Products – Induction Machines. One has to make an account with an e-mail address and a password to get access to the catalogue.

Very long ago a Dutch manufacturer of asynchronous motors has given me a page of a German folder on which an overview is given of the armature and stator dimensions depending on the frame size and the number of poles. This page can't be found on the website of Feintool but it is very handy to make a choice, especially because it also gives the armature and stator length L_{Fe}. I have scanned it and added it as figure 7. It is a bit dirty and full with remarks but it still works. D_a is the outside diameter of the stator stamping. D_i is the inside diameter of the stator stamping. d_i is the diameter of the hole in the armature stamping. The frame size is the height of a foot B3 from the centre of the shaft up to the bottom of the foot.

The outside diameter of the armature is somewhat smaller than D_i because of the air gap in between armature and stator but the value isn't given as this is chosen by the manufacturer of the motor. The number of stator slots is also not given but I have written it on the sheet it for some frame sizes. This information is given on the website of Feintool if one goes to the selected stamping.

Leistungsangaben in KW bei 50 Hz nach DIN 42 673 und 42 677

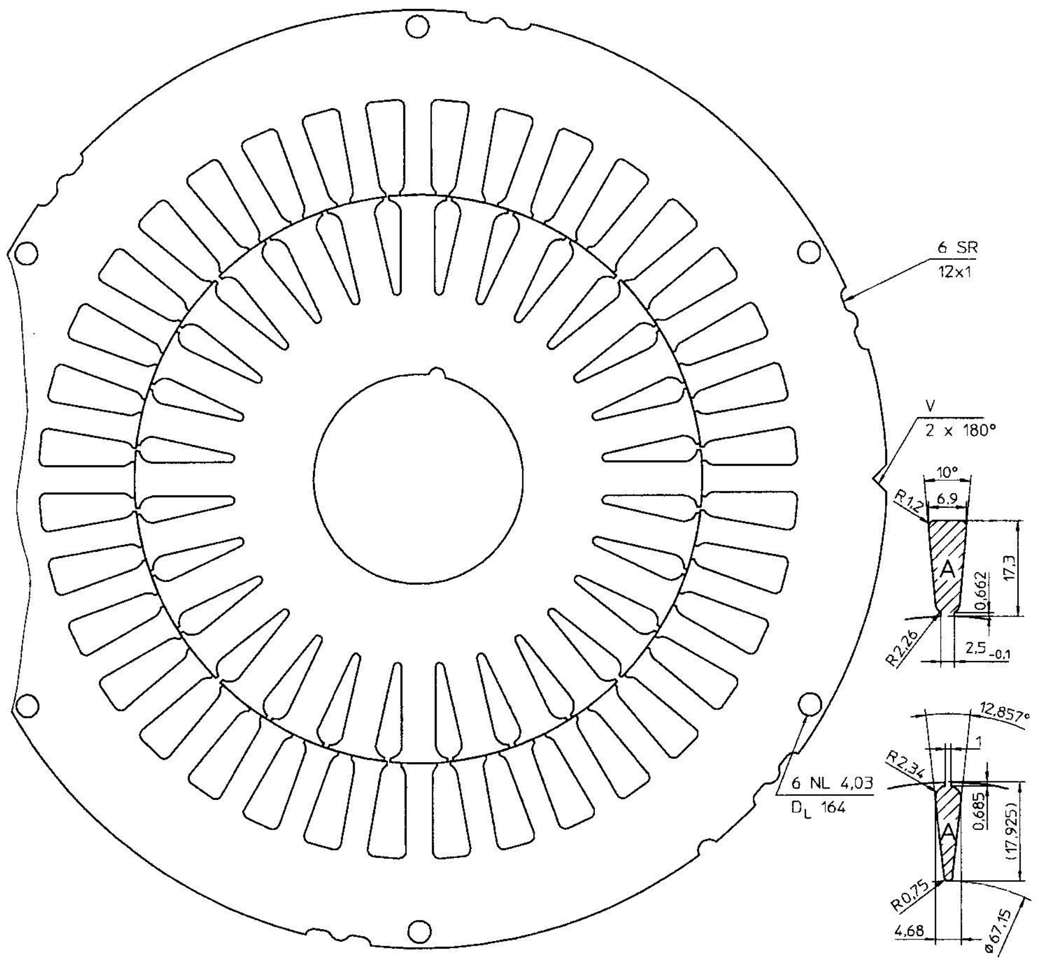
Baugröße / Frame size / Hauteur d'axe	2-polig 3000 min⁻¹ KW	Da / Di / di	mm LFe	4-polig 1500 min⁻¹ KW	Da / Di / di	mm LFe	6-polig 1000 min⁻¹ KW	Da / Di / di	mm LFe	8-polig 750 min⁻¹ KW	Da / Di / di	mm LFe
56	0,09 0,12	80 40 15	45 55	0,06 0,09	80 45 15	45 55	0,04 0,06	80 50 15	45 55	0,03 0,04	80 50 15	45 55
63	0,18 0,25	90 45 18	45 60	0,12 0,18	90 50 18	45 60	0,09 0,12	90 55 18	45 60	0,06 0,09	90 55 18	45 60
71	0,37 0,55	106,5 55 20	50 65	0,25 0,37	106,5 62 20	50 65	0,18 0,25	106,5 70 20	50 65	0,12 0,18	106,5 70 20	50 65
80	0,75 1,1	120 62 25	60 80	0,55 0,75	120 70 25	60 80	0,37 0,55	120 80 25	70 90	0,25 0,37	120 80 25	70 90
90 S	1,5	135 70 30	75	1,1	135 80 30	75	0,75	135 90 30	75	0,45	135 90 30	75
90 L	2,2		100	1,5		100	1,1		100	0,55		100
100 L	3	150 80 36	90	2,2 3	150 90 36	90 120	1,5	150 103 36	120	0,75 1,1	150 103 36	90 120
112 M	4	170 90 38	110	4	170 103 38	140	2,2	170 115 38	140	1,5	170 115 38	140
132 S	5,5 7,5	200 110 50	90 120	5,5	200	125	3	200	125	2,2	200	100
132 M				7,5	125 50	170	4 5,5	135 50	150 180	3	140 50	135
160 M	11 15	240 135	130 180	11	240 150	160	7,5	240 165	165	4 5,5	240 170	125 165
160 L	18,5	55	215	15	55	215	11	55	225	7,5	55	225
180 M	22	270 150 65	190	18,5	270 170 65	200		270 180 65			270 190 65	
180 L				22		240	15		240	11		240
200 L	30 37	300 170 75	200 250	30	300 190 75	250	18,5 22	300 200 75	230 265	15	300 215 75	265
225 S		340 190 80		37	340 215 80	240		340 240 80		18,5	340 240 80	240
225 M	45		240	45		290	30		290	22		290
250 M	55	375 215 85	240	55	375 240 85	290	37	375 260 85	290	30	375 270 85	310
280 S	75	420 240 95	250	75	420 270 100	300	45	420 290 100	275	37	420 305 100	300
280 M	90		300	90		360	55		330	45		360
315 S	110	500 290 115	275	110	500 325 115	300	75	500 375 115	300	55	500 375 115	300
315 M	132 160		330 400	132 160		370 470	90 110 132		370 450 550	75 90 110		370 450 550
355 S	200 250	580 325	370 470	200 250	580 375	370 450	160 200	580 425	470 550	132 160	580 425	470 550
355 L	200 250 315	120	370 470 550	200 250 315	130	370 450 550	160 200	130	470 550	132 160	130	470 550

Kienle+Spiess Stanz- und Druckgießwerk GmbH

fig. 7 Overview of the geometries of the armature and stator stampings of asynchronous motors using a stator stamping of Kienle & Spiess (Feintool)

Frame size 112 M is mentioned at figure 7. The outside diameter D_a of the stator stamping is 170 mm for all pole numbers. The inside diameter D_i of the stator stamping depends on the pole number and is 103 mm for a 4-pole motor. A 4 kW motor has a stator with a length of 140 mm. The stator stamping has 36 slots. The synchronic rotational speed is 1500 rpm for a grid frequency of 50 Hz.

The armature stamping has the same length as long as only the iron stamping sheets are taken into account. However, aluminium bars are cast into the armature stamping and these bars are connected at both sides of the armature by an aluminium disk with cooling fins at the outside. The real length of the armature is therefore much longer than the stator length. A detailed picture of the chosen armature and stator stamping is given on the website of Feintool and this picture is copied and given as figure 8.



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IEC 112/4.103		Maße und Varianten					
		D_a		D_i	N	A	b_z
SB 170.07.X00		170 +0,08		103 ±0,043	36	92,6	4,9
01	6 NL. o SR		05	6 SR. o NL			
RB 103.09.Y.00				d_a	N	A	b_z
d_i				103	28	53,6	6.2
01	38 +0,039	02	30 +0,033	03	40 +0,039 M		
07	25 +0,033	09	36 +0,039 M	12	45 +0,039 M		
Blechdicke SB und RB		0,35/0,5/0,65					

These lamination drawings are meant for information only. PDF or DXF data will be provided upon request.
Dies ist eine unverbindliche Schnittzeichnung. PDF oder DXF Daten erhalten Sie auf Anfrage.

fig. 8 Stamping Feintool IEC 112, 4-pole

In figure 8 it can be seen that the stator stamping has 36 slots and so 36 mechanical stator poles. So the angle in between the mechanical stator poles is 360 / 36 = 10°. In figure 8 it can be seen that the armature has 28 slots and so 28 mechanical armature poles. So the angle in between the mechanical armature poles is 360 / 28 = 12.8571°.

The number of magnetic stator and armature poles depends on the stator winding. It is assumed that the standard 230 / 400 V, 3-phase winding of a 4-pole motor is used and so the stator and the armature will have four magnetic poles. The magnetic armature pole angle for a 4-pole PM-generator is 360 / 4 = 90°. The winding of a 4-pole motor is a so called two layers winding. An example of such a winding is given in figure 1.

In figure 8 it can be seen that the short-circuit armature has 28 slots in which the aluminium short-circuit bars are cast. These aluminium short-circuit bars don't guide a magnetic field. So the magnet grooves must be chosen such that they lay in between the aluminium bars. It is chosen to use magnets for both the north and the south poles.

It is chosen to use neodymium magnets size 40 * 7 * 3 mm. These magnets are supplied by the Polish company Enes Magnets website: www.enesmagnets.pl. The magnet quality is N38 which means that the remanence B_r is about 1.24 T. The tolerance on the dimensions is ± 0.1 mm and so the groove width must be made 7.2 mm to guarantee that a magnet will always fit in a grove. The current price (February 2024) including VAT but excluding costs of transport is € 0.55 per piece if a minimum number of 180 magnets is ordered.

The distance in between two adjacent aluminium bars is calculated and it was found that it is about 6.2 mm. So a 7 mm wide magnet seems a good choice. The magnetic stator pole angle is 360 / 4 = 90°. This corresponds to 9 mechanical stator poles. An armature pole angle of 90° corresponds to 7 armature poles if the armature has 28 aluminium bars. This ratio 7 : 9 prevents preference positions.

In figure 8 it can be seen that the distance in between two adjacent armature slots is constant for the main part of the slots but that an armature pole is widened at the outside. This means that small iron particles of the stator stamping are left if a 7.2 mm wide and 3.3 mm deep groove would be made in between the aluminium bars. A groove depth of 3.3 mm makes that the air gap is larger than 0.3 mm, even at the corners of the magnets. The small iron particles can be difficult to remove. So it is decided to first reduce the armature diameter from 102.4 mm up to 98.4 mm and to use grooves with a depth of 1.3 mm. This gives the same outside diameter measured at the corners of the magnets. After turning the armature to a diameter of 98.4 mm, the aluminium bars are crossed at almost the maximum width and so the small aluminium lines have become wide aluminium lines. An advantage of 1.3 mm deep grooves is that 1.3 mm deep grooves can be made much faster than 3.3 mm deep grooves.

The stator slots are in parallel to the motor axis. However, the armature slots are not. This isn't visible in figure 8, but for all short-circuit armatures which I have seen, the armature stamping is twisted such that there is just one stator pitch overlap of the slots in between the left and the right side of the stamping. This is done to prevent fluctuation of the torque with a high frequency. So if you look at the small line (for the original armature diameter) formed by an aluminium bar at the outside of the armature, you will see that it makes a small angle with the armature axis. The line isn't straight but it is a helical line although the difference in between a straight line and a helical line is very small. The angle can be calculated easily if it is assumed that it is a straight line. The inside diameter of the stator is 103 mm. So the inside stator circumference is 103 * π = 323.58 mm. So the stator pole pitch is 323.58 / 36 = 8.99 mm. The armature length is 140 mm. So for the angle ϕ in between the aluminium line and the armature axis it is valid that ϕ = inv tg 8.99 / 140 = 3.67°. It must be checked by measuring if this angle is really used for the given armature.

It seems simplest to give the magnet grooves this angle. However, this would mean that the groove depth is maximal at the centre of the armature but that it is less deep at the sides of the armature and that the magnets will jut out of the grooves at the sides of the armature if the grooves aren't made deep enough. This problem can be solved almost completely by giving each magnet its own groove.

The magnets have a length of 40 mm and the armature has a length of 140 mm. Assume that three magnets are used in one row. So the armature length available for one magnet is 140 / 3 = 46.67 mm. Assume that it is chosen to take a distance of 6.5 mm in between the magnets in one row and a distance of 3.5 mm in between a magnet and the side of the armature. These distances can be used to give each magnet its own groove. Assume that the grooves are made with a 7.2 mm cutter and that the groove depth is 1.3 mm to be sure that the maximum armature diameter measured around the corners of the magnets is less than 102.4 mm. Three levels are distinguished.

The groove heart of level 1 has a distance of 23.5 mm from the left side of the armature.
The groove heart of level 2 has a distance of 70 mm from the left side of the armature.
The groove heart of level 3 has a distance of 116.5 mm from the left side of the armature.

One starts with the grooves of level 1. So the heart of these grooves lay at a distance of 40 / 2 + 3.5 = 23.5 mm from the left side of the armature. The groove must be made just in the middle of two adjacent aluminium lines under an angle of 3.67° with the shaft axis. The armature shaft has to be mounted in a turn table with a horizontal shaft for which the angle of rotation can be adjusted accurately. The first groove has a length of the part for which the sides are in parallel of 40 mm. So the total length including the curved ends is 47.2 mm if a cutter with a diameter of 7.2 mm is used.

After making the first groove, the armature is rotated 360 / 28 = 12.8571° and next the second groove of level 1 is made. This procedure is followed until all 28 grooves of the first level are made.

The angle in between two different levels is 360 / (36 * 3) = 3.3333°. Next the armature is rotated 3.3333° in the direction which corresponds to the direction of the aluminium lines. Next the cutter is shifted to the second level which lies at a distance of 70 mm from the left side of the armature and the 28 grooves of level 2 are made following the same procedure as described for level 1. The same procedure is followed for the 28 grooves of level 3.

So totally 3 * 28 = 84 grooves are made. So totally 84 magnets are needed resulting in a total magnet costs of about € 47 without costs of transport, which is very low for a PM-generator of this size.

There will be a small overlap in the curved parts of the grooves for adjacent levels as there is a distance of 6.5 mm in between adjacent magnets but this won't be a problem.

The magnets are glued in the grooves by epoxy glue or by anaerobe glue such that they have the right position and such that the north pole of the 42 magnets is facing outwards and that the south pole of the other 42 magnets is facing outwards.

It is advised to first lay the 42 magnets of the north poles. One has to develop a tool with which a magnet can be held on both 40 * 3 mm sides during mounting. The magnet must jut 1.5 mm out of the tool to make it possible to push the magnet up to the bottom of the groove.

The stator stamping is provided with six 4.03 mm holes at a pitch circle of 164 mm. These holes can be used to press all sheets together but they are a resistance for the magnetic flux. The resistance can be reduced if 4 mm iron rods are put in these holes but I don't know if this is possible if the winding has already been laid. The problem with these six holes is less for a 4-pole armature than for a 6-pole armature as for a 6-pole armature, there is a position every 60° of the armature for which the resistance is minimal and this position will cause a preference position. For a 4-pole armature this happens only for two holes at the same time and so the effect of causing a preference position every 30°, will be much less.

The volume of one magnet is 0.84 cm^3. So the total magnet volume = 84 * 0.84 = 70.56 cm^3. The magnet volume of the magnets 40 * 15 * 5 mm as used for the 16-pole generator as described in chapter 2 is 3 cm^3. 28 magnets are used for one armature and so the total magnet volume is 84 cm^3 which is higher.

However, magnets are only used for the north poles and the magnet thickness in one magnetic loop is 5 mm. The total magnet thickness in one loop is 6 mm for the 28-pole generator but the total magnet length in one groove is 120 mm instead of 140 mm. However, the average thickness of the air gap is smaller for 7 mm wide magnets than for 15 mm wide magnets. I expect that the maximum torque level of the 28-pole generator is a bit smaller than that of the 16 pole-generator. One has to measure a prototype to check if the characteristics match with the VIRYA-3B3 rotor.

Using the original armature makes that one eliminates the material, manufacturing and mounting costs of a big mild steel bush. This 28-pole generator might therefore be cheaper than the 16-pole version, especially if only one generator is made. The fact that the magnet grooves are inclined and that the ratio in between the mechanical armature poles and the mechanical stator poles is 7 : 9, makes that this 28-pole generator will have almost no peak on the cogging torque and this reduces the starting wind speed. The 16-pole generator will have some peak on the cogging torque and so the starting wind speed will be higher.

As magnets are used for the north poles and for the south poles, the whole outside of the armature has to be covered with a thin layer of epoxy lacquer to prevent that the nickel coating of the magnets is scratched when the armature is mounted in the stator.

A cross section at the heart of the armature and a side view of three rows of magnets are given in figure 9. The aluminium bars are not given in the cross section.

The ideas as given in this report KD 718 to transform a 4-pole asynchronous motor into a PM-generator can also be used for a 6-pole asynchronous motor. Some examples of such a transformation are given in report KD 747 (ref. 9).

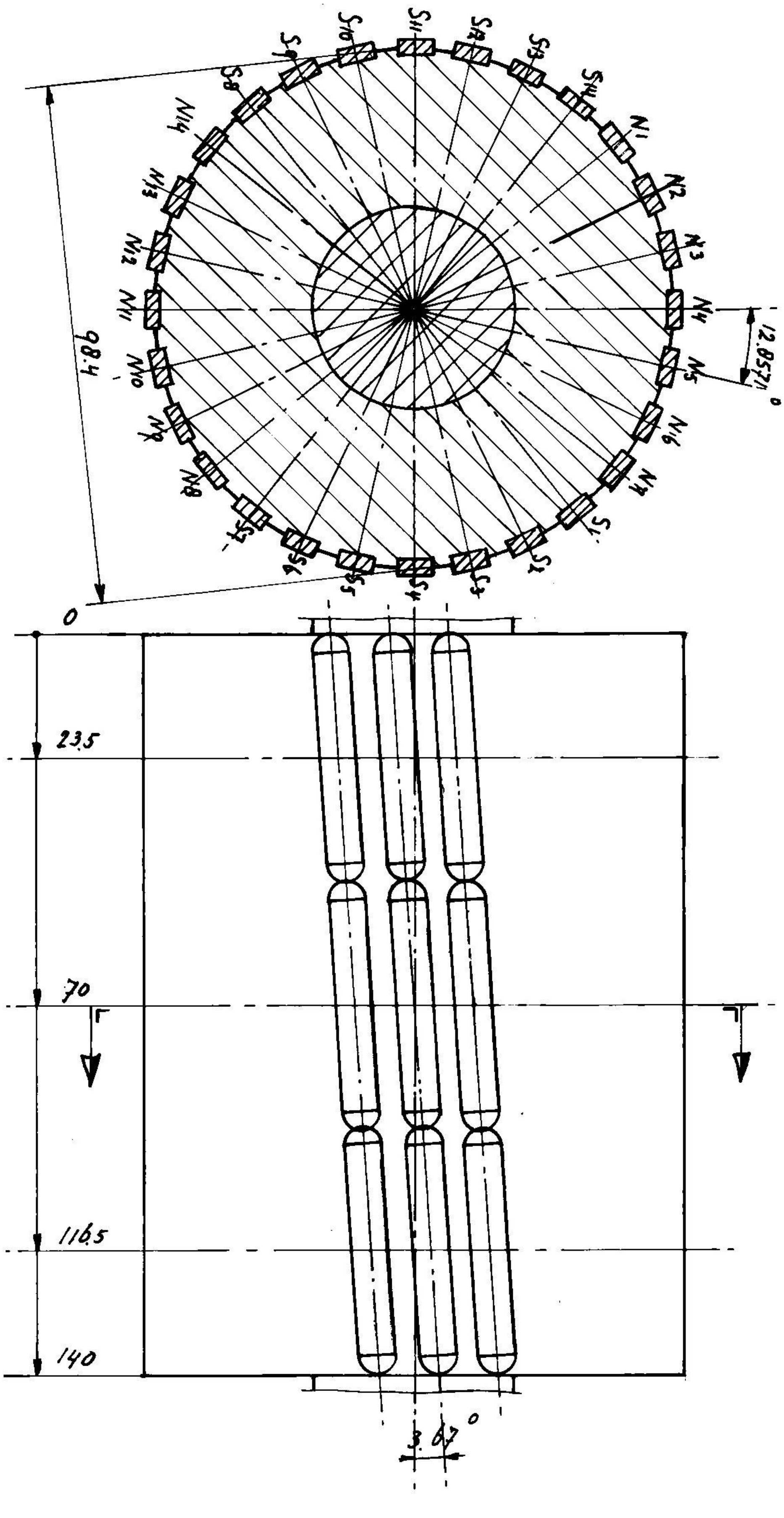


fig. 9 PM-armature for 4-pole motor frame size 112 M
(aluminium short-circuit bars not drawn in cross section)

11 Use of a 4-pole motor frame size 132 and a 28-pole original armature

The same principle as used in chapter 10 for a motor frame size 112, can also be used for frame size 132. However, larger magnets have to be used. Assume magnets of Enes Magnets size 40 * 10 * 10 mm with quality N38 are used. The price of these magnets is € 1.78 (April 2025) if at least 80 magnets are ordered. As these magnets are rather thick, it is possible to use magnets only for the north poles.

Frame size 132 M is mentioned at figure 7. The outside diameter D_a of the stator stamping is 200 mm for all pole numbers. The inside diameter D_i of the stator stamping depends on the pole number and is 125 mm for a 4-pole motor. A 7.5 kW motor has a stator with a length of 170 mm. The stator stamping has 36 slots. The synchronic rotational speed is 1500 rpm for a grid frequency of 50 Hz.

The armature stamping has the same length as long as only the iron stamping sheets are taken into account. However, aluminium bars are cast into the armature stamping and these bars are connected at both sides of the armature by an aluminium disk with cooling fins at the outside. The real length of the armature is therefore much longer than the stator length. A detailed picture of the chosen armature and stator stamping is given on the website of Feintool and this picture is copied and given as figure 10 in which two magnets are drawn.

In figure 10 it can be seen that the stator stamping has 36 slots and so 36 mechanical stator poles. So the angle in between the mechanical stator poles is 360 / 36 = 10°. In figure 10 it can be seen that the armature has 28 slots and so 28 mechanical armature poles. So the angle in between the mechanical armature poles is 360 / 28 = 12.8571°.

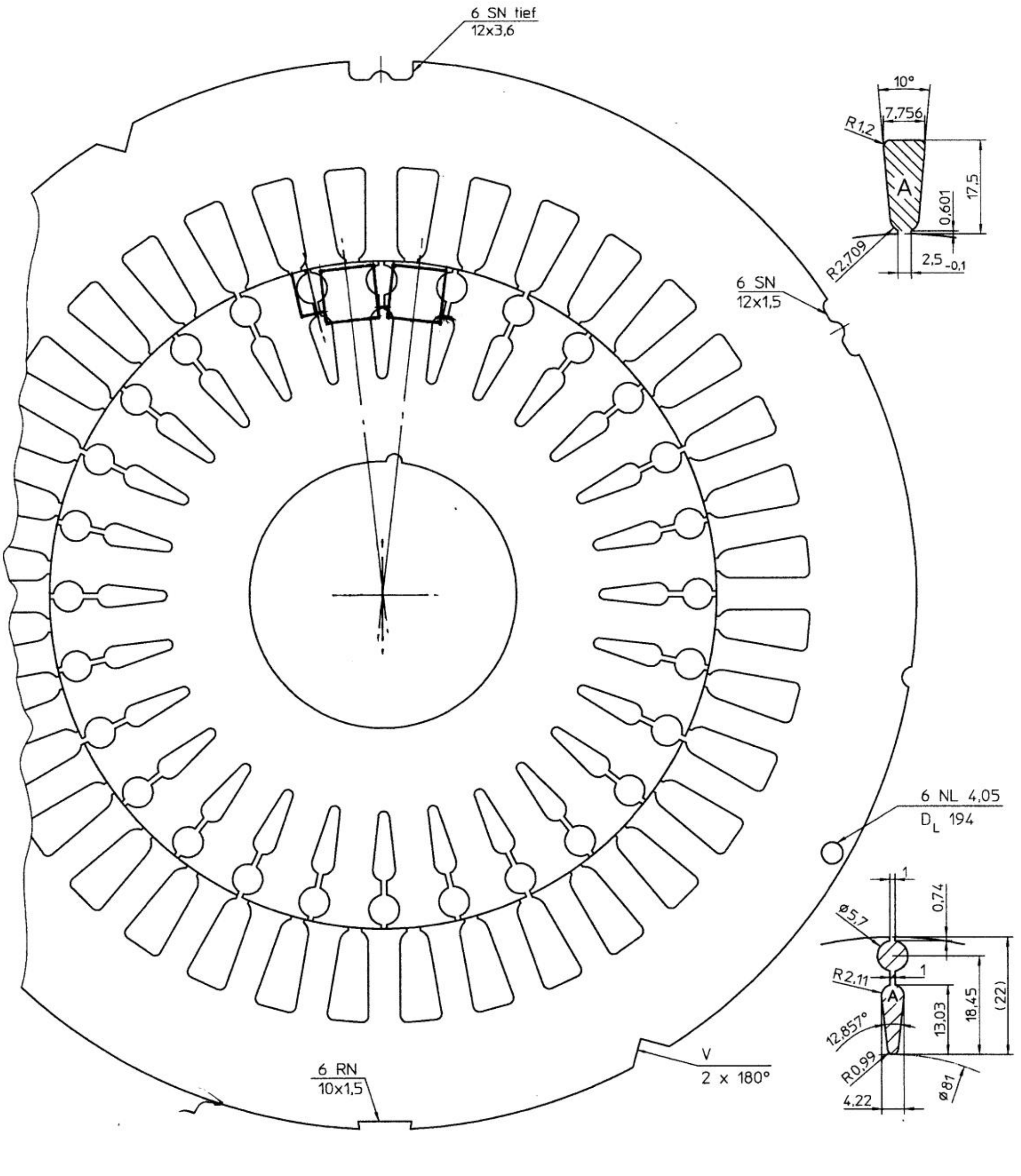
The aluminium short-circuit bars have a different shape as the short-circuit bars in the armature stamping of a motor frame size 112. At the outside there is circular part and at the inside there is a tapered part. Making 10.2 mm wide grooves in between the circular parts would result in many small iron particles. Therefore first eight 6 mm wide and 8.5 mm deep grooves are made at the aluminium short-circuit bars. The seven magnet grooves are made afterwards just in between these 6 mm wide grooves. The procedure to give each magnet its own groove as it is done for the generator with frame size 112, would also be complicated. So it is decided to put four magnets in one groove.

As the stator length is 170 mm and as the magnet length is 40 mm, there is enough place for four magnets in one groove. Four magnets have a total length of 160 mm and so 10 mm of the groove isn’t used. The magnets are positioned such that there is a distance of 2.5 mm in between adjacent magnets and a distance of 1.25 mm in between a magnet and both sides of the armature stamping.

The magnet groove must be that deep that the magnets don’t jut out of the armature. If one groove is used for four magnets, the air gap will be bigger at the heart of the armature than at the sides. It is assumed that the original armature has a diameter of 124.4 mm and so the air gap is 0.3 mm. It is assumed that the magnet grooves have a depth of 10.8 mm at the heart of the armature. The magnet grooves must make a certain angle of inclination with the shaft axis. This angle is such that there is just one stator pitch overlap at the left and the right side of the stator. The stator has 36 slots and so 36 mechanical poles. The inside diameter of the stator is 125 mm. So the pitch in between the stator poles is π * 125 / 36 = 10.91 mm. The stator length is 170 mm. For the angle of inclination α it is valid that α = inv tan 10.91 / 170 = 3.67°. It has to be checked if this calculated angle is the same as the real angle in between the aluminium short-circuit bars and the armature axis.

The shift of the groove at the side of the armature related to the centre of the armature is half the stator pole pitch and so 5.45 mm. It has been calculated that the air gap at the corner of a magnet at the side of the armature is about 0.32 mm and so a groove depth of 10.8 mm is a good choice. The air gap at the heart of the armature and the heart of a magnet is 1.1 mm. The average air gap at a north poles formed by four magnets will be about 0.9 mm. The air gap at the south poles is 0.3 mm. So the total air gap is 1.2 mm. The remanence of a magnet with quality N38 is about 1.24 T.

A total air gap of 1.2 mm results in a calculated flux density in the air gap of 1.24 * 10 / 11.2 = 1.11 T which is very high and therefore it can be expected that the stator stamping is saturated which results in a high peak torque level.



IEC 132/4.125	Maße und Varianten				
	D_a	D_i	N	A	b_z
SB 200.06.X.00	200 +0,09	125 ±0,05	36	107,5	6
01	6 NL, o RN, o SN	05	6 RN, o NL, o SN		
09	6 SN, o NL, o RN	11	6 SN tief, o NL, o RN		
RB 125.06.Y.00		d_a	N	A	b_z
d_i		125	28	67,7	7,3
01	49,96 +0,02/-0,03 M	02	44 +0,039 M	03	40 +0,039 M
06	35 +0,039 M	14	42 +0,039 M		
Blechdicke SB und RB	0,5				

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These lamination drawings are meant for information only. PDF or DXF data will be provided upon request.
Dies ist eine unverbindliche Schnittzeichnung. PDF oder DXF Daten erhalten Sie auf Anfrage.

fig. 10 Stamping Feintool IEC 132, 4-pole with two magnets and one 8.5 mm deep groove

The distance in between two tapered adjacent aluminium bars is about 7.5 mm. So a 10 mm wide magnet has some overlap with the aluminium bars at the sides of the magnet but this is no problem as the magnetic flux will be concentrated in the iron in between the aluminium bars. The magnetic stator pole angle is 360 / 4 = 90°. This corresponds to 9 mechanical stator poles. An armature pole angle of 90° corresponds to 7 armature poles if the armature has 28 aluminium bars. This ratio 7 : 9 in combination with the inclined angle of the groove will prevent preference positions almost completely.

There are four magnets in one groove and there are seven grooves for one north pole. So the total number of magnets required is 4 * 7 * 2 = 56. So the total magnet costs are about 56 * € 1.78 = € 100. This is rather low for a PM-generator of this size.

The magnets are glued in the grooves by epoxy glue or by anaerobe glue such that they have the right position and such that the north pole of all magnets is facing outwards. One has to develop a tool with which a magnet can be held on both 10 * 10 mm sides during mounting.

The stator stamping is provided with six 4.03 mm holes at a pitch circle of 194 mm. These holes can be used to press all sheets together but they are a resistance for the magnetic flux. The resistance can be reduced if 4 mm iron rods are put in these holes but I don’t know if this is possible if the winding has already been laid. The problem with these six holes is less for a 4-pole armature than for a 6-pole armature as for a 6-pole armature, there is a position every 60° of the armature for which the resistance is minimal and this position will cause a preference position. For a 4-pole armature this happens only for two holes at the same time and so the effect of causing a preference position every 30°, will be much less.

The volume of one magnet is 4 cm^3. So the total magnet volume = 56 * 4 = 224 cm^3. The magnet volume of the magnets 40 * 10 * 5 mm as used for the 32-pole generator as described in chapter 7 is 2 cm^3. 64 magnets are used for one armature and so the total magnet volume is 64 * 2 = 128 cm^3 which is a factor 128 / 224 = 0.571 lower. But the total magnet thickness in one magnetic loop for the 32-pole generator is 5 mm and for the 28-pole generator it is 10 mm. So it can be expected that the 28-pole generator is stronger and will have a higher maximum torque level. Another advantage of the 28-pole generator is that the original armature is used and so no big iron bar is needed. One has to measure a prototype to check if the characteristics match with the VIRYA-4.2B3 rotor as described in KD 769 (ref. 7).

It is advised to cover the magnets with a layer of epoxy lacquer to prevent that the nickel coating of the magnets is scratched when the armature is mounted in the stator. A cross section at the heart of the armature and a side view of three of the seven rows of magnets are given in figure 11. The aluminium bars aren’t given in the cross section.

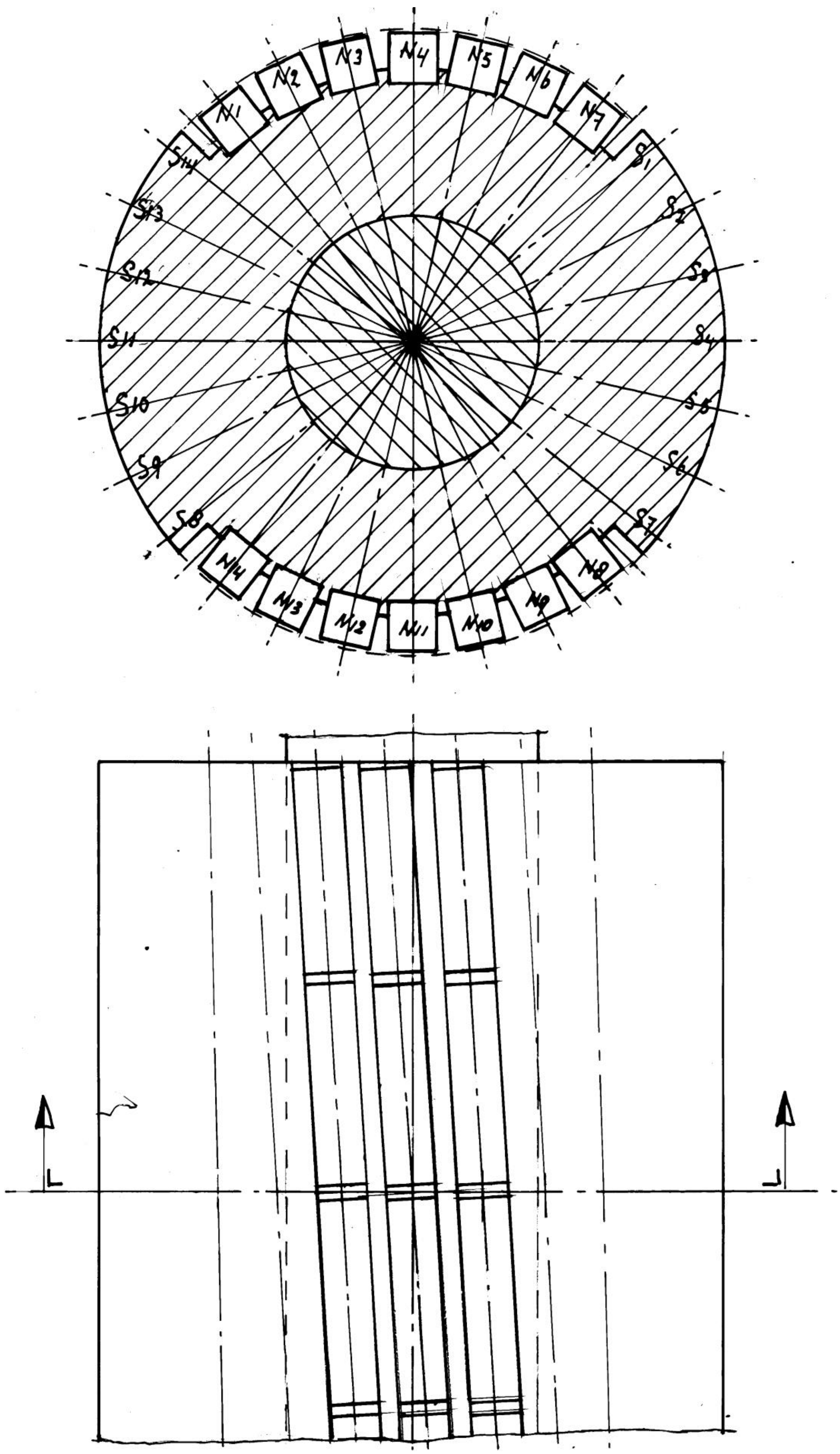

fig. 11 PM-armature for 4-pole motor frame size 132 M
(aluminium short-circuit bars not drawn in cross section)

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