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Specialized in designing small electricity generating windmills and PM-generators

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Ideas about an ideal hub dynamo

1 Introduction

This note starts with the description of four simple tests which I have performed to the dynamos of two bikes. The first bike is my old Batavus Apache which is provided with an 8-pole tire dynamo type AXA HR and for which there is a 2.4 W, 6 V halogen bulb in the headlight. The second bike is my wives Koga Miyata Randonneur which is provided with a 28-pole NEXUS hub dynamo and for which the headlight also contains a 2.4 W, 6 V halogen bulb. A bike was hung such that the front wheel is some cm free from the ground. A hard push was given to the front wheel and it was measured how long it takes until the wheel stops.

The first test was done with the Batavus with the tire dynamo free from the tire. It took about 110 seconds for the wheel to stop. For the second test the dynamo was touching the tire. The AXA HR tire dynamo has a ribbed rubber wheel and an accelerating gear ratio of about 19 : 1. It took about 2.5 seconds for the wheel to stop and the lamp was burning during the first second. The lamp wasn’t flickering which is because the frequency of the generated voltage is rather high and because a halogen bulb has a filament with a certain mass which flattens the generated heat.

The third test was done with the Koga Miyata with hub dynamo. The head lamp of this bike is provided with a switch with which the light can be set on or off. The light was off for the third test. It took about 25 seconds fro the wheel to stop. The light was on for the fourth test. It took about 12 seconds for the wheel to stop. In the beginning the light was burning continuously but at the end it was flickering.

The following can be concluded from these tests. The wheel was turning longest for the first test without a tire dynamo because the wheel was only slowed down because of the bearing friction and the aerodynamic friction in between the air and the wheel. The needed power for the aerodynamic friction increases with the cube of the rotational speed and the maximum speed which can be gained by pushing the wheel by hand is that low, that the aerodynamic friction can almost be neglected. Most power is therefore needed for the bearing friction but this friction is low for well adjusted ball bearings. This is why a wheel without a tire dynamo turns very long.

If the tire dynamo is on, the wheel turns only very shortly. The bearing friction of the wheel is now augmented with the friction of the tire dynamo. The friction of the tire dynamo is caused by the friction of the transmission, the friction of the sleeve bearings of the dynamo and the magnetic losses in the dynamo stator. If the dynamo supplies power, also a certain torque is needed to supply this power.

For the hub dynamo, the time for light off is about double the time for light on. However, the time for light off is much shorter than for a wheel without a tire dynamo. This is an indication that a hub dynamo has important magnetic losses. The time with light on is much longer than the time for a tire dynamo and a burning light.

This is because a tire dynamo has extra friction in the transmission and the sleeve bearings. The advantage of a tire dynamo is that no power is needed if the dynamo is not touching the tire. So for a hub dynamo there are always magnetic losses even if the lamp is off and I see this as an important disadvantage. To be able to understand the cause of these magnetic losses, the internal construction of a hub dynamo has to be researched. At a bike fair, I have seen an open hub dynamo and it has the following components.

A steel bush is pressed in the aluminium housing to which the spokes are connected. A large number on neodymium magnets are glued at the inside of this bush such that there is alternately a north and a south pole at the inner side. I assume that the tested Nexus hub dynamo had 28 magnets and so 14 north poles and 14 south poles. Around the shaft, there is one big coil. At both sides of this coil, there is a fluke armature made from several layers of thin iron sheet. Every fluke armature has 14 flukes and is bent such that at the inside it is lying at the inside of the coil and at the outside it is positioned close to the magnets. The 14 flukes of the left fluke armature are falling exactly in between the 14 flukes of the right fluke armature. At a certain position of the armature, there is a magnetic flux flowing through the heart of the coil from left to right. However, if the armature has rotated for one armature pitch, the magnetic flux is flowing from right to left. This results in the generation of an alternating voltage in the coil.

The constant change of the direction of the magnetic field in the two fluke armatures results in magnetic losses. For an ideal hub dynamo, there is therefore no iron in the coils. However, without fluke armatures, it isn’t possible to guide the magnetic flux such that it is flowing through one central coil. An ideal hub dynamo must therefore have a total different construction and in chapter 2, a possible construction is described.

I have designed many permanent magnet (PM) generators for small wind turbines and some of them have been measured extensively. An overview of the PM generator which I have developed is given in public report KD 341 which can be copied for free from my website: www.kdwindturbines.nl at the menu KD-reports. Recently I have designed some generators for which there is no iron in the coils and those generators gave me the idea for the ideal hub dynamo.

There is a certain similarity in between a wind turbine generator and a hub dynamo. I have even developed a small windmill, the VIRYA-1.04, which makes use of a NEXUS hub dynamo. The construction drawings of this windmill (and of six others) are released and can be copied for free from my website. Some years ago, ten VIRYA-1.04 windmills have been built by students of the UT-Twente. One of these windmills is shown on the photo below. At the menu VIRYA-folders, there is a separate folder in which these seven released windmills are described

2 Description of a new type hub dynamo

The most recent PM-generator without iron in the coils which I have designed, is described in report KD 645. For this 10-pole generator, the rotating armature is at the inside and the stator with coils is at the outside. For a hub dynamo, this is inconvenient and the armature with magnets must be positioned at the outside, just as it is the case for a normal hub dynamo. Now I will describe the ideal hub dynamo as I have it in mind. My starting points were:
1) The dynamo is direct drive which means that it contains no accelerating gearing.
2) The dynamo should not be larger than a modern hub dynamo.
3) The stator contains no iron and therefore no eddy currents will be generated.
4) A 3-phase alternating current is generated which is rectified.
A rectified 3-phase alternating current has only a limited fluctuation of the voltage. The frequency of the fluctuation is six times higher than the frequency of one of the phase voltages. The variation of the voltage of a rectified 3-phase voltage is given in figure 9 of report KD 340 for rectification in star. This figure is copied as figure 1.

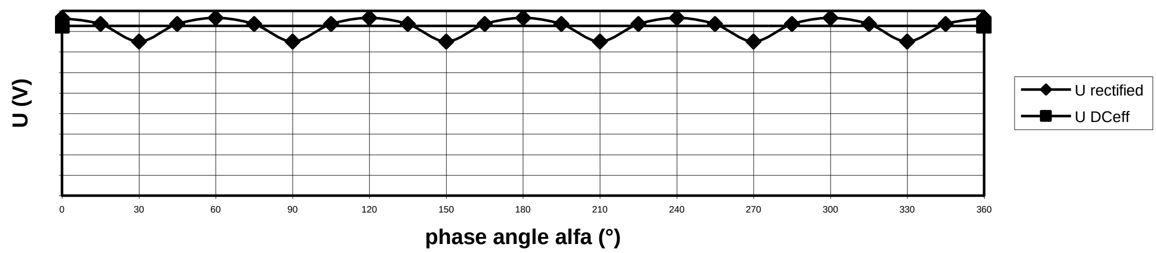

Figure 1 Variation of a 3-phase alternating voltage rectified in star

For a rectified 3-phase alternating current, the dynamo can have a relatively low number of poles without inconvenient flickering of the light at low rotational speeds. Therefore it is chosen for a 12-pole dynamo for which twelve magnets are required.

Because there is no iron in the coils, the dynamo has a large air gap in between the magnets. The magnetic field which is flowing through the coils becomes smaller if the air gap is bigger and if the magnets are thinner. To realise a sufficiently strong magnetic field in the coils, the magnets therefore must be rather thick. It is decided to use magnets which are standard available and a choice must be made in between different suppliers. I prefer the Polish supplier ENES Magnesy because this company has a very large assortment of neodymium magnets and because the magnets of this company are rather cheap. It is chosen to take a magnet size 30 * 10 * 5 mm which has as quality N42. The remanence Br of this quality is about 1.3 T. The remanence is the magnetic flux density in Tesla (T) when the magnet is short-circuited by an iron bridge which isn't saturated. An air gap results in reduction of the flux density but calculation of the influence of the air gap on the flux density in the coil is out of the scope of this note. However, the method is given in KD 645.

The price of the chosen magnet is € 0.69 including VAT but excluding costs of transport if at least 80 magnets are ordered. For manufacture of bigger quantities of dynamos, the magnet costs for one dynamo are about € 9 which sounds realistic to me. In this note, I restrict myself to only the construction of the armature with magnets and the stator with coils. The construction of the bearings and the connection of the dynamo in the front fork of the bicycle must be worked out later.

The twelve magnets are glued in a steel bush which is made out of seamless steel pipe size 60 * 2.5 mm. This bush is pressed into the aluminium housing of the dynamo. The bush has an inside diameter of 55 mm and a width of 30 mm. So the width is equal to the length of the magnets. Twelve 10 mm wide and at the heart 0.1 mm deep grooves are made at the inside of the bush and the magnets are glued in these grooves.

The circle which is touching the inside of the magnets has a diameter of 45.2 mm for a groove depth of 0.1 mm. The magnets are positioned such that alternating six north and six south poles are created. The thickness of the bush has to be chosen rather large to prevent that the iron of the bush is saturated. If the iron would be saturated, this reduces the strength of the magnetic field which is flowing through the coils. I have checked if the iron is saturated and that isn't the case.

Twelve closed magnetic loops are coming out of the twelve magnets. Every magnetic loop is flowing through the steel bush, next through half a north pole, next through the air at the inside of the armature and next through half a south pole. Six magnetic loops are turning right hand and six magnetic loops are turning left hand. It is assumed for the part of a magnetic loop which is flowing through air, that it has about the shape of a circle segment.

The stator in which the coils are lying, is a synthetic bush made from a material like Delrin. The bush has an outer diameter of 44 mm. The circle which is touching inside the magnets has a diameter of 45.2 mm and the air gap in between the bush and the magnets is therefore 0.6 mm. The bush has a length of 30 mm, so identical to the length of the steel bush. The bush is pressed on the shaft or axially fixated. The shaft is hollow at one side and the wires coming from the coils are guided to the outside through the hollow shaft.

The stator has a 1-layer, 3-phase winding with three coils per phase. The advantage of a 1-layer winding is that there are no crossing coil heads. This makes that the coil heads can be very small and this limits the width of the stator. The coils are laid in a synthetic stator which is provided with nine grooves at the outside. The grooves are lying in parallel to the shaft. Every groove has a width of 8 mm and a depth of 5 mm. The grooves are numbered 1 – 9. A coil has a left and a right arm and a front and a back coil head. The left arm of a certain coil is lying together with the right arm of the adjacent coil in the same groove. Therefore only nine grooves are required for nine coils.

The angle in between the heart of two adjacent magnets is 30° for a 12-pole armature. The angle in between the heart of two stator grooves is 40°. However, the left coil arm is lying in the right part of the groove and the right coil arm is lying in the left part of a groove. The average pitch angle in between the left arm and the right arm is therefore also about 30°. So if a north pole is passing the left arm of a coil, a south pole is passing the right arm of a coil. This means that the voltage generated in the left arm is in phase to the voltage generated in the right arm and this gives the maximum voltage for a certain rotational speed and a certain number of turns per coil.

The three phases are called U, V and W. The nine coils are lying in the sequence U1, V1, W1, U2, V2, W2, U3, V3 and W2 and make use of the grooves with respectively the numbers (1 + 2), (2 + 3), (3 + 4), (4 + 5), (5 + 6), (6 + 7), (7 + 8), (8 + 9) and (9 + 1). A front view and a cross section of the armature and the stator is given in figure 2.

The armature is drawn in the position for which the north pole N1 is opposite the groove 1. In figure 2 it can be seen for this position that north pole N2 is opposite coil V1, that north pole N4 is opposite to coil V2 and that north pole N6 is opposite to coil V3. So the voltages generated in the three coils of one phase are in phase to each other and can therefore be added if all coils have the same winding direction. The three coils of one phase are wound outside the generator on a winding thorn and therefore have the same winding direction on the thorn. The coils have to be mounted in the stator such that the winding direction is the same.

The three phase windings are soldered together in star. The soldering connection of the star point is isolated and is lying somewhere in between the coil heads. So only three wires are coming out of the shaft of the dynamo and these wires are connected to a 3-phase rectifier. It might be an option to position the rectifier in the dynamo. In this case only two wires are coming out of the dynamo and there is a DC voltage in between these wires.

For a 12-pole armature, the armature is in the same magnetic position if it is rotated over 1/6 of a revolution, so over 60°. Therefore an armature angle β = 60° corresponds to a phase angle α = 360°. So the phase angle α is six times the armature angle β.

In figure 2 it can be seen that β = 20° for the armature angle in between N1 and U1. So the corresponding phase angle α is 120°. In figure 2 it can be seen that β = 40° for the armature angle in between N2 and W1. So the corresponding phase angle α is 240°. Therefore a 3-phase current is generated in between the coils U1, V1 and W1.

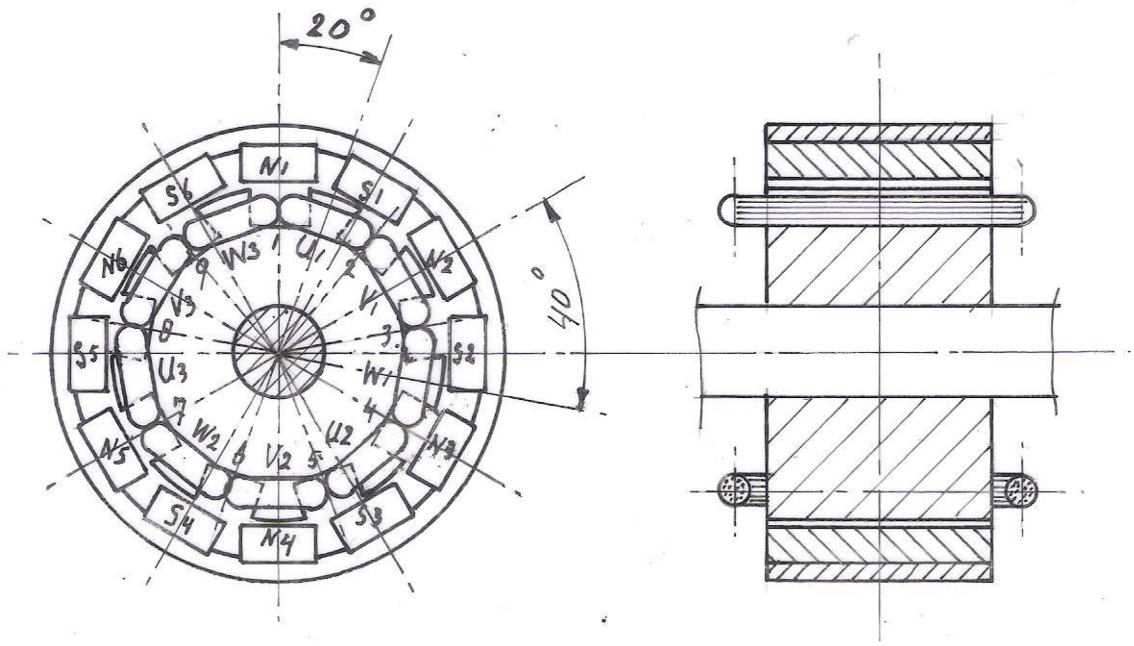

Figure 2 Armature and stator of a 12-pole, 3-phase hub dynamo

A 3-phase rectifier contains six diodes of which only two are guiding a current at the same time. The most common rectifiers contain silicon diodes and in the guiding direction, there is a voltage drop of about 0.7 V over each diode. So over the whole rectifier there is a voltage drop of about 1.4 V. This is rather high if the lights burn at a voltage of 6 V and this means that there is a substantial loss of power in the rectifier. The generator will have a high efficiency because there are no iron losses but it is a pity to loose a lot of the generated power in the rectifier. This problem can be reduced by using a rectifier which is equipped with germanium diodes or so called Schottky diodes. The voltage drop for a germanium diode is only about 0.3 V. The voltage drop for a Schottky diode is in between 0.15 V and 0.46 V.

It must be prevented that the wires which are lying in the groove move outwards and touch the rotating armature. For asynchronous motors, one uses closing caps to prevent this but in this case, the width of the groove must be reduced at the entrance. This seems no practical idea for a synthetic stator. It seems possible to pull the nine coils heads inwards at both sides of the stator by a thin rope. It may be required to submerse the whole stator in lacquer afterwards.

After rectification, the dynamo supplies a DC voltage with almost no fluctuation and therefore it can be used for 6 V incandescent lamps but also for LED lamps. To supply a sufficient high voltage at a moderate cycling speed, a rather large number of turns per coil will be required. The determination of the optimal number of turns per coil is out of the scope of this note but can be found by try and error. The maximum power which can be supplied at a moderate cycling speed can only be determined if a prototype is available. I think that it will be substantial higher than for a normal hub dynamo.

Because the dynamo supplies an almost fluctuation free DC voltage, it can also be used to charge a 6 V battery. This is important for people which make long cycling trips and which take a GPS with them which has to be charged regularly.

If the battery is almost full, it must be prevented that it is over charged and therefore some advanced electronics will be needed. If the dynamo is only used to power light, some electronics may also be required to prevent that the voltage becomes too high at high cycling speeds resulting in burning of the lamp.

A 1-phase alternating current can also be rectified if one wants to use LED lamps but the DC current and the DC voltage will fluctuate strongly (see figure 5, KD 340). Because LED lamps react very fast on voltage fluctuations, they will therefore flicker at low frequencies. Another disadvantage of a LED lamp is that it is a diode and therefore a single diode uses only one part of the sinus. A single LED lamp therefore doesn’t burn during half the time and the frequency of the flickering is therefore the same as the frequency of the sinus. The frequency with which a halogen lamp flickers, is equal to two times the frequency of the sinus because the generated power is maximal at the highest and at the lowest voltage.

The human eye can’t follow the flickering if the frequency is higher than about 25 Hz and this frequency occurs with a halogen lamp at half the driving speed as for a LED lamp. Because halogen lamps have a filament which has a certain mass, a fluctuating light yield is also flattened better than for a LED lamp. This is the reason why halogen lamps are used in combination with hub dynamos, at least if no extra electronics are used to rectify the alternating current and to flatten the fluctuation.

Because of the thick magnets and the 3-phase stator winding, this 12-pole hub dynamo will be more expensive than most other normal hub dynamos. But it has unique qualities and I expect that people who appreciate these qualities will be willing to pay that higher price for this dynamo. If the extra costs is compared to the price of a complete bike, the extra costs will be limited.

The idea of this new hub dynamo is made public. Anyone is allowed to develop generators of this type and commercialize it. I have no intention to do it myself but I want to give advice to someone who wants to do this.