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Ideas about an ideal hub dynamo

Modern hub dynamos have, compared to tyre dynamos, certain clear advantages like a much higher efficiency when the light is on, a slip free transmission and a non vulnerable construction in the hub of the front wheel. However, they also have certain disadvantages like loss of energy if the light is off caused by eddy currents in the stator lamination, a low frequency of the generated 1-phase alternating current resulting in flickering of the light at low rotational speeds, a strongly pulsating torque which can give vibrations and noise at high rotational speeds and, depending on the manufacture, a rather high price.

The first three disadvantages are the result of the fact that a permanent magnetic (PM) armature is used of which the magnetic field is guided through a central coil by means of iron claws. A 1-phase AC current is generated in the coil. These disadvantages can be eliminated if the stator, in which the coils are lying, contains no iron and if in stead of a 1-phase AC current, a 3-phase AC current is generated which is rectified. For my wind turbines, I have recently developed several PM-generators for which the coils contain no iron. Those generators therefore have a low sticking torque and a high efficiency. These generators are described in chapter 6 of report KD 341 which can be copied for free from my website www.kdwindturbines.nl. The development of those generators suggested the idea to me for, as I see it, 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

The VIRYA-1.04 using a NEXUS hub dynamo as generator

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.

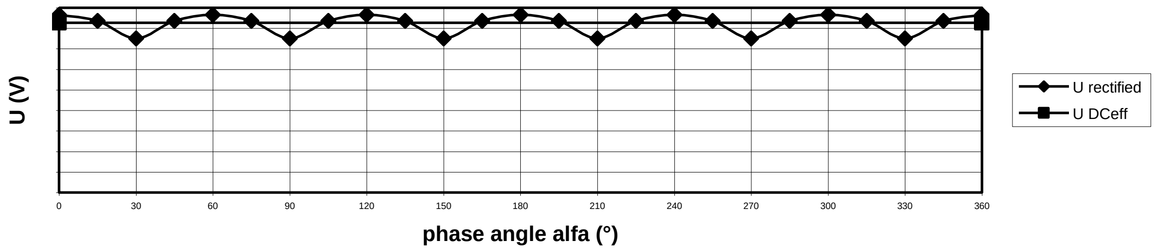

Figure 1 Variation of a 3-phase alternating voltage rectified in star

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 10-pole dynamo for which 10 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 25 * 10 * 5 mm which has as quality N38. The remanence Br of this quality is about 1.24 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 € 0,79 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 € 8 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 ten 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 25 mm. So the width is equal to the length of the magnets. Ten 10 mm wide and at the heart 0.1 mm deep grooves are made at the inside of the bush under an angle of 36°. 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 five north and five 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.

Ten closed magnetic loops are coming out of the ten 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. Five magnetic loops are turning right hand and five 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 25 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 of a 3-phase winding for a 10-pole armature is provided with 12 grooves at the outside which are in parallel to the shaft. The grooves are numbered 1 – 12. A groove has a width of 6 mm and a depth of 7 mm, so there is space for rather thick coils. Every coil needs two grooves, so six coils can be laid in twelve grooves. So there are two coils for each phase. A coil has two arms which are lying in the grooves and a coil head at the left and at the right side which connect the arms. The angle in between the heart of two adjacent magnets is 36° for a 10-pole armature. The angle in between the heart of the left and the right arm of a coil is only 30° and the voltage generated in the left arm is therefore not exactly in phase to the voltage generated in the right arm. But a difference in angle of 6° gives only a very limited reduction of the summarised voltage in both arms.

The three phases are called U, V and W. A so called 1-layer winding is used what means that there are no crossing coil heads. The six coils are lying in the sequence U1, W2, V1, U2, W1 and V2 and make use of the grooves with respectively the numbers (1 + 2), (3 + 4), (5 + 6), (7 + 8), (9 + 10) and (11 + 12). 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 coil U1. In figure 2 it can be seen that the south pole S3 is opposite to coil U2 for this position. Both coils are wound outside the stator on a winding thorn and therefore both coils have the same winding direction on the thorn. However, the coils have to be mounted in the stator such that winding direction is different because otherwise the voltages won't strengthen each other.

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 10-pole armature, the armature is in the same magnetic position if it is rotated over 1/5 of a revolution, so over 72°. Therefore an armature angle β = 72° corresponds to a phase angle α = 360°. So the phase angle α is five times the armature angle β. In figure 2 it can be seen that β = 24° for the armature angle in between N3 and V1. So the corresponding phase angle α is 120°. In figure 2 it can be seen that β = 48° for the armature angle in between N5 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.

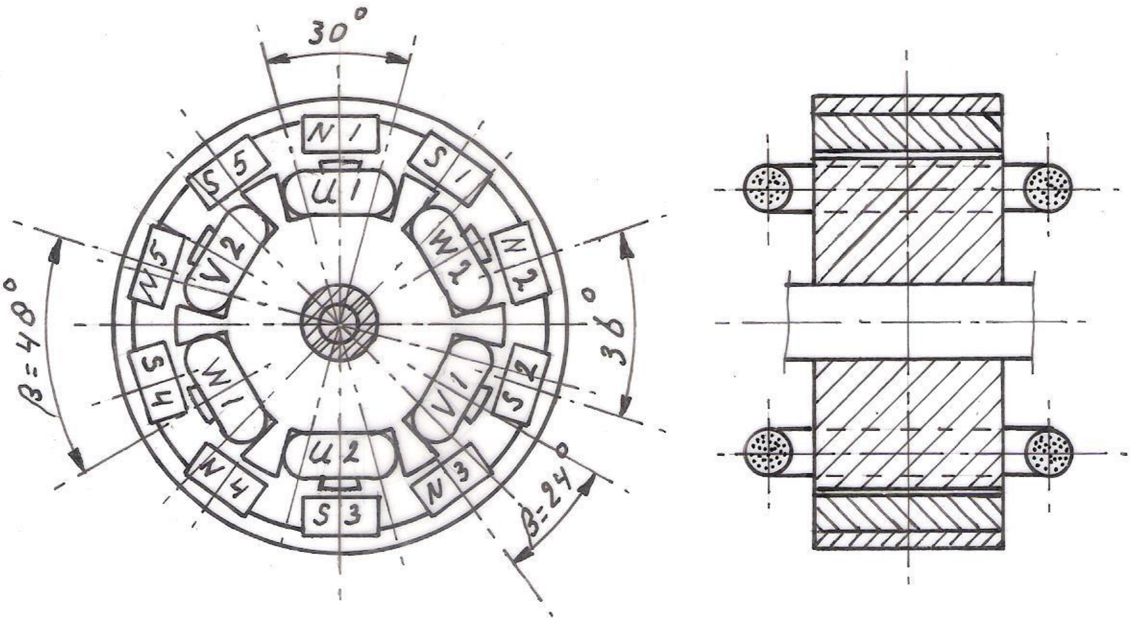

Figure 2 Armature and stator of a 10-pole, 3-phase hub dynamo

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 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 six coils heads inwards at one side 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.

If it appears that the generated power is too high, shorter magnets size 20 * 10 * 5 mm can be chosen and the length of the armature bush and the stator bush must be chosen 20 mm. If it appears that the generated power is too low, longer magnets size 30 * 10 * 5 mm can be chosen and the length of the armature bush and the stator bush must be chosen 30 mm. An advantage is that 30 mm long magnets are even cheaper than 25 mm long magnets. However, a wider stator is only possible if there is enough space in between the bearings and if the larger weight is no problem. An alternative is to use twelve magnets and a stator with nine coils which all have the same winding direction. The coil sequence is now U1, V1, W1, U2, V2, W2, U3, V3 and W3. In this case the stator is provided with nine, 8 mm wide and 5 mm deep grooves and two windings are lying together in one groove.

Because the dynamo supplies an almost fluctuation free DC voltage, it can also be used to charge a 6 V battery. 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 therefore will flicker at low frequencies (except if capacitors are used).

Because of the thick magnets and the 3-phase stator winding, this 10-pole hub dynamo will certainly be more expensive than most of the other normal hub dynamos. But it has unique properties and I expect that those who favour these properties are willing to pay more for this dynamo. The higher costs will be limited if compared to the costs of a whole bicycle.

The idea of this new hub dynamo is now made public. Anyone is free to develop hub dynamos according to this principle and put it on the market. I have no plans to develop the dynamo myself but I am willing to support those who wants to do this.