Investigation of the Sparta Ion front wheel hub motor as generator for a small wind turbine

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1 Introduction

On the wind forum of Otherpower website https://fieldlines.com there has been a discussion about the usability of a Sparta Ion front wheel hub motor. The discussion is started in the post of mbrouwer titled “axial generator with lamination core” at page 21, Replay #599. At this point, a photo is shown of a hub motor from which the bearing cover at the cable side is removed. The two printed circuit boards are removed too. In this photo it can be seen that the motor has an armature with 20 magnets and so 20 poles and a stator with 24 coils. It appears that the coils are connected such that the winding is a 3-phase winding. The three ends of the phases can be seen as three red isolated threaded holes in the bottom of the hub.

On YouTube there is a Dutch video of someone who has modified this motor by removing both internal printed circuit boards and who has connected a 3-phase cable directly to the 3-phase winding. He drives the motor with a standard 3-phase inverter. The video is called: ”Sparta Ion GD Design”.

It might be possible to use this hub motor as generator for a small wind turbine which can charge a 12 V lead acid battery. However, this will only work acceptably if the generator has a sufficiently low peak on the cogging torque and if P_{mech}-n curve of the generator matches with the optimum cubic line of the chosen wind turbine rotor. Matching in between rotor and generator is explained in chapter 8 of my public report KD 35 (ref. 1).

To get an impression of the qualities of this hub motor, I have bought a complete second hand front wheel (for only € 20). I have removed the rim and the spokes.

2 Description of the generator

The motor comes from the front wheel of an about ten years old Dutch E-bike Sparta Ion. This bike wheel has no brake at the motor but a brake on the wheel rim. There are E-bikes with an about identical motor at the back wheel but this motor has a longer shaft and a set of chain sprockets and sometimes also a brake connected to the motor. Therefore a front wheel motor was chosen.

The motor is direct drive and has an outside armature with 20 poles and a 3-phase stator with 24 coils. There are two printed circuit boards inside the hub which contain the inverter and the electronics needed for the torque regulation. There is a type plate in between the spoke flanges indicating: ION technology Hub motor 24-36 V, 250 W, Accell NL B.V.

The cable side of the motor is called the back side. The motor has two flanges to which the spokes are connected. Every flange has eighteen, 3 mm holes for the spokes at a pitch circle of 178 mm. The outside diameter of the flanges is 192 mm. The diameter at the heart of the hub is about 166 mm but it is a little hollow and there is a radius of about r = 3 mm with the flanges. The front bearing cover has a diameter of about 165 mm but there is a large radius r = 5 mm with the front flange.

The shaft has a diameter of 12 mm at the bearings but near the end, the diameter is reduced to 10 mm and both ends have a fine thread with an outside diameter of about 9 mm and a flat side at which the thickness is only 8 mm. In the 12 mm diameter part of the shaft there is a 6 mm wide and about 4 mm deep groove through which the cable is guided inside the bearing. In between the back bearing and the bicycle frame there is a bush with an outside diameter of 22 mm and the cable is guided through a groove in this bush. This bush increases the stiffness of the shaft if the nut is tightened. The shaft is made of high quality steel but the groove weakens the shaft strongly.

In a bicycle, the shaft is supported at both sides but if this motor is used as a generator for a wind turbine, only the back shaft end will be used to connect the generator to the head frame. I think that a rotor diameter of 1.5 m is the absolute maximum for this shaft and then this is only allowed if the wind turbine is provided with the hinged side vane safety system which limits the rotational speed and the yawing speed and so the gyroscopic moment.

3 Measuring of the cogging torque

The first thing which I did was measuring of the cogging torque. The back side shaft end was clamped in a vice. The hub has a diameter at the heart of the two flanges of 166 mm. A thin chord was wound around the hub and a hook was made at the end of the rope. Different ring spanners were hang at the hook until the hub just starts rotating. The spanners were weighed on a digital balance. The hub starts rotating at a weight of 850 gr = 0.85 kg. The radius of the string is 166 / 2 = 83 mm = 0.083 m. So for the peak torque Q_{peak} it is valid that: Q_{peak} = 9.81 * 0.083 * 0.85 = 0.692 Nm which is very high. In report KD 78 (ref. 2), I give the measurements for a PM-generator made from an asynchronous motor frame size 90. This generator has a shaft diameter of 25 mm and can be used for a rotor with a diameter of 3 m. The cogging torque at n = 0 rpm is only 0.4 Nm.

It was also measured which weight is needed to keep a slowly rotating hub running, once it has started to rotate. This is the case for a weight of 387 gr = 0.387 kg. So for the average torque Q_{av} it is valid that Q_{av} = 9.81 * 0.083 * 0.387 = 0.315 Nm. This is less than half the peak value. A photo of these measurements is given in figure 1.

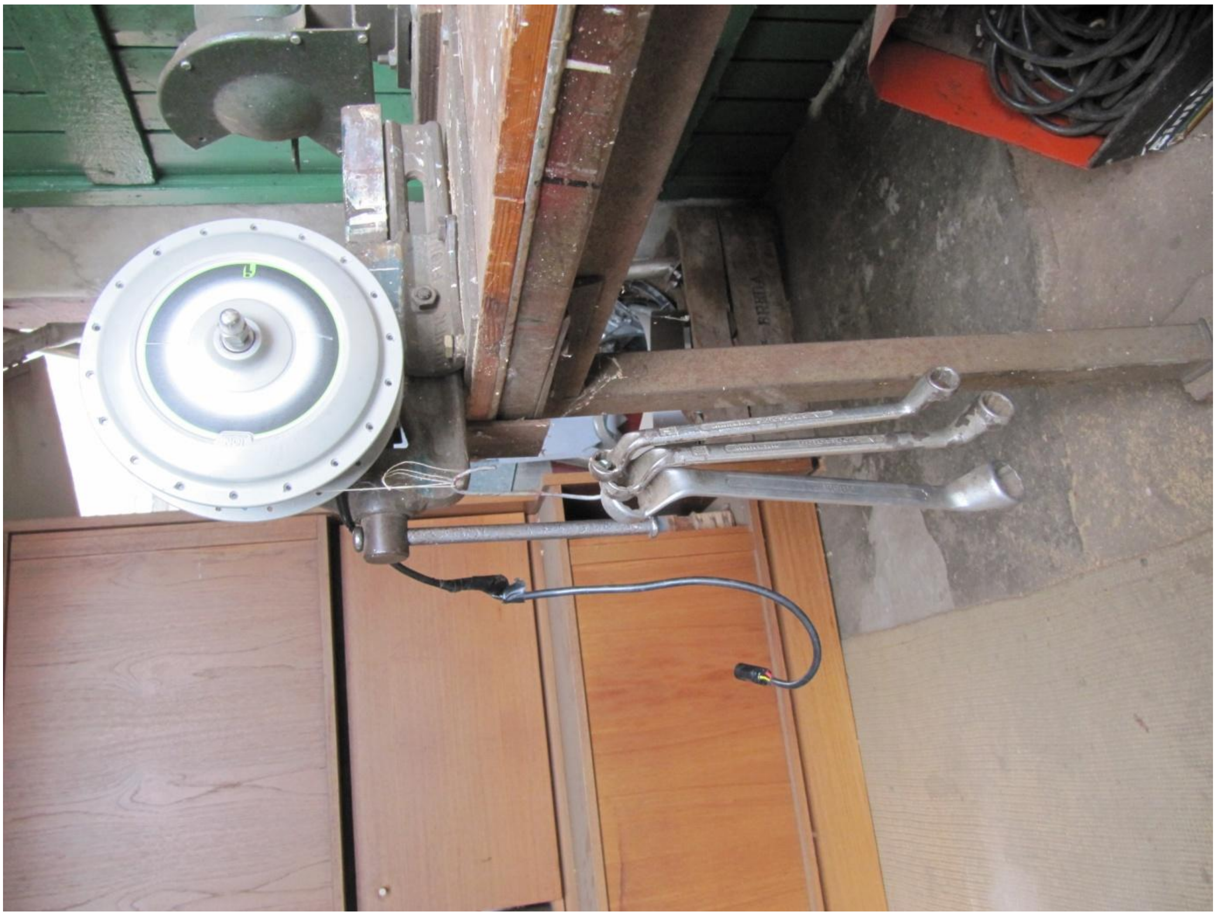

fig. 1 Measuring of the cogging torque.

As the armature has 20 poles, the angle in between two adjacent poles is 360 / 20 = 18°. As the stator has 24 poles, the angle in between two adjacent poles is 360 / 24 = 15°. So the difference is 3°. Assume that the armature has a preference position if an armature pole is just opposite a stator pole. This happens every 3° for four armature poles at the same time and so the armature should have 360 / 3 = 120 preference positions per revolution. However, in practice it appears that the armature has only 20 preference positions per revolution. I don’t quite understand how this is possible.

It might be caused by the fact that the magnets are not exactly positioned under 18°. A slight deviation from the theoretical angle may make one of six preference positions stronger than the other five and only the strongest one is felt.

4 Measuring of the open voltage

The next thing was to check if a non modified motor can supply a DC voltage when it is used as a generator. Three cables with colours red, black and yellow are coming out of the back shaft. These three cables are not directly connected to the three phases of the winding. The cables with colours red and black are normally connected the battery. The inverter is built in the hub motor on the second printed circuit board. It is assumed that the 3-phase winding is connected in star and that the star point is hidden somewhere at the coils. The yellow cable is used to regulate the torque. A DC volt meter was connected to the red and black wires. A swing was given to the rope and the DC voltage became about 20 V. So the 3-phase inverter also works as a 3-phase rectifier. However, the voltage slows down only slowly for n = 0 rpm which is an indication that there are capacitors inside the generator.

To really measure the U-n curve, it is necessary to drive the motor with different constant rotational speeds. But this requires a test rig with which the generator can be driven. Some years ago I have built a simple test rig to measure a small Chinese axial flux PM-generator of Hefei Top Grand. This test rig is described in report KD 595 (ref. 3).

The test rig makes use of a permanent magnet DC motor which is driving a second shaft using a reducing chain transmission to increase the torque level. Unfortunately there is some non concentricity in the big chain wheel which makes that the tension in the chain varies and this causes vibrations which limits the maximum rotational speed. The motor can be driven at variable speed using a Variac and a 1-phase rectifier. The rotational speed is measured using a laser speed meter. The second shaft is made black with a white reflecting spot on it.

The second shaft has a hub with a hole pattern of the Chinese generator. A hexagonal 2 mm thick steel plate is bolted to this hub with three bolts M8. The Sparta hub motor is bolted to this sheet by six threaded rods M5 which are that long that the front shaft end of the hub motor isn’t touching the hexagonal sheet.

So six of the eighteen spoke holes in the front flange are increased up to 5 mm. It was chosen to take that holes which are opposite the six screws which connect the back bearing cover. The hub was supported on three wooden blocks during drilling (see photo given in figure 2).

The flange has a rather large radius at both sides of the flange and some aluminium is filed away to create flat areas large enough for a nut M5 at both sides of the flange. Filing is also easy if the generator is lying on the three wooden blocks.

The sheet of the test rig is clamped in a vice. A symmetric lever is bolted to the shaft end and one end of the lever is connected by a rope to a weight lying on the ground. This prevents that the shaft is rotating. A photo of the test rig is given in figure 3.

First it was thought that the generator can’t be coupled to a 12 V lead acid battery because then it might work as a motor. However, nothing happens if the red wire is connected to the plus and if the black wire is connected to the min of the battery. It appears that the generator works only as a motor if the correct signal is given to the electronics by means of the yellow wire. So if a battery is mounted, charging starts as soon as the open voltage is higher than the battery voltage. However, it isn’t sure if the electronics on the printed circuit boards are strong enough for long use of a non modified motor as generator. It might still be required to remove both printed circuit boards, to lay a new 3-phase cable and to use an external 3-phase rectifier. The six diodes in a 3-phase rectifier make that there can only flow a current from the generator to the battery and not in the opposite direction.

fig. 2 Drilling of six 5 mm holes

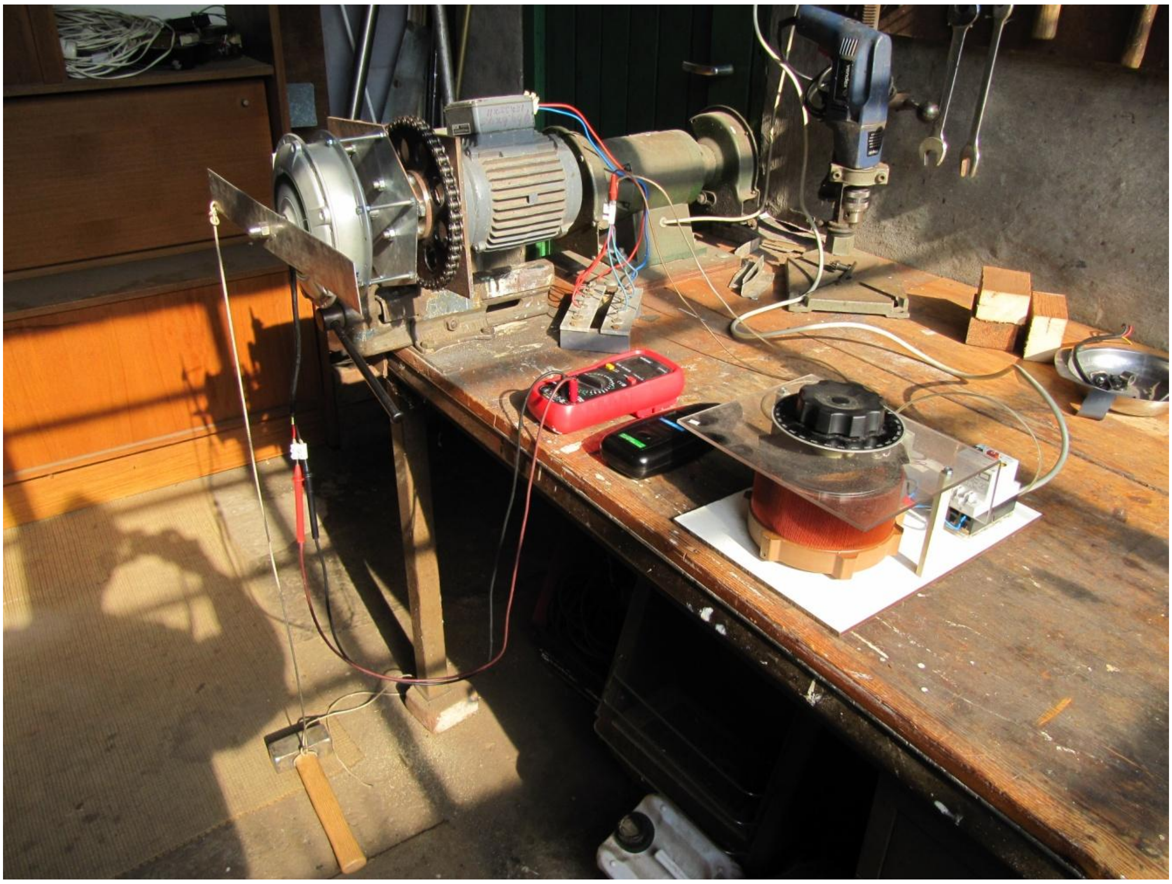

fig. 3 Test rig for measuring of the open voltage

The measured open voltage U_{open} (V) as a function of the rotational speed n (rpm) is given in figure 4.

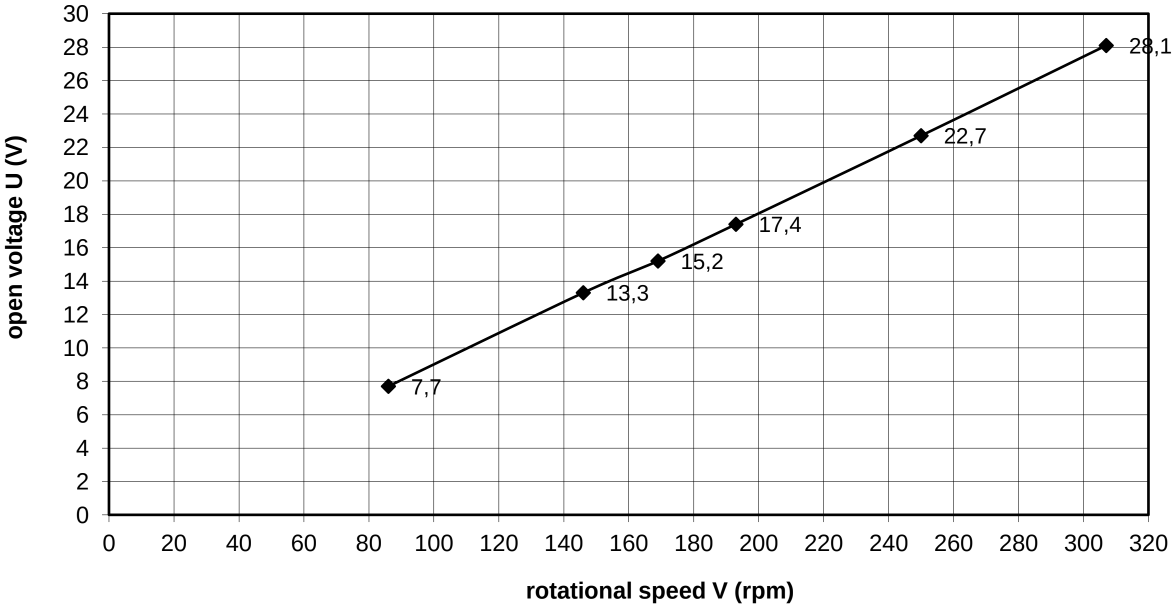

fig. 4 Open voltage U (V) as a function of rotational speed n (rpm) for a standard motor

Charging of a 12 V lead acid battery starts about at an open voltage of 13 V. In figure 4 it can be seen that this voltage is reached at a rotational speed of about 143 rpm. So at this rotational speed the P_{mech}-n curve of the generator suddenly rises. To find the P_{mech}-n curve for a 12 V battery load, the torque Q has to be measured. This is possible for the described test rig if the weight at the end of the rope is laid on a balance.

However, I stopped the measurements at this point because the very large peak on the cogging torque is a big problem. I made some calculations for different rotors and I found that it is very difficult or even impossible to design a rotor with a maximum diameter of 1.5 m and a sufficiently high design tip speed ratio which has a starting torque coefficient which is high enough to get an acceptable low starting wind speed. The weak shaft may also break if the moment in the shaft is too high. So my conclusion is that this hub motor can’t be used as a generator for a small wind turbine. Therefore I won’t take the effort to measure the P_{mech}-n and P_{el}-n curves for a 12 V battery load.

5 References

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3 Kragten A. Measurements performed on a Chinese axial flux generator of Hefei Top Grand model TGET165-0.15kW-500R for a 12 V battery load, September 2015, reviewed December 2021, free public report KD 595, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.