A Novelty Design of an Axial Flux Induction Electrical Machine with Low Manufacturing Cost

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***Abstract*— the paper considers a novelty design of an axial flux induction electrical machine that ensures high efficiency with relatively low manufacturing cost. The low manufacturing cost is based on the construction being made from a single thin pieces of electro conductive and magneto conductive materials. Thus a stator is defined from a spirally wound single sheet of electrical steel to form the greater part of the magnetic core of the stator with additionally formed trapezoidal sheets of electrical steel thus creating a magnetic core for the stator coils. In turn the rotor is itself made again with a spirally wounded sheet of electrical steel creating the main part of the magnetic core of the rotor. Again the magnetic cores of the rotor teeth are made from thinly cut sheets of electrical steel and the rotor cage is created by casting aluminum or copper and having on inner and one outer rotor bar rings to create the squirrel cage. Thus the construction does not require specialty tooling for the manufacturing of the main components even for different axial and radial dimensions of the machine.**

***Keywords*— novelty, design, axial flux induction machine, electrical machine, low manufacturing**

I. Introduction

The goal of the study is the creation of an asynchronous induction electrical machine with an axial orientation of the magnetic flux. Additionally, this axial induction machine will have a novelty design lowering its manufacturing cost by removing the need for special tools (cutting dies) for the manufacturing of a lamination structure of the stator and rotor for each specific size.

Another aim of the study is the modification of a UPS system with a flywheel kinetic accumulator – a flywheel. Having an axial flux induction electrical machine which can work both as a motor or a generator is beneficial because it will make it possible to implement the machine inside the flywheel construction thus making it more compact and having the ability to stack onto each other such flywheels given that the novelty design. Doing this allows for a better ratio concerning power and weight as well as allowing for a more than sufficient cycle of charging and discharging. [1] [2].

The creation of this axial flux electrical machine is based on a 3D FEA model with of a 6-pole axial flux asynchronous induction electrical machine having a variable frequency drive (VFD) at 150 Hz thus rotating the machine at 2895 rpm.

II. Preexisting Test bed for Novelty Asynchronous Axial Flux Induction Electrical machin

A test bed will be used that is created with a radial electrical machine. The test bed functions as UPS system with a Kinetic Energy Accumulator. The construction of the system as well as an exploded view of the custom electrical radial machine are shown on figures 1 through figure 3.

The system is comprised of a flywheel (pos. 4) attached by a collet (pos. 5) to the front end of the rotor of a 22kW asynchronous induction electrical machine (pos. 1). The flywheel (pos. 4) is located in a welded housing (pos. 2), which is ribbed to provide additional stiffness to the structure and is closed with a flanged cover (pos. 7).

The UPS system has a radial induction electrical machine as noted with pos. 1. The electrical machine is positioned onto a welded housing (noted as pos. 2) and a kinetic energy accumulator in the form of a flywheel mass (pos. 4) is mounted to its rotor with the use of a collet (pos. 4)

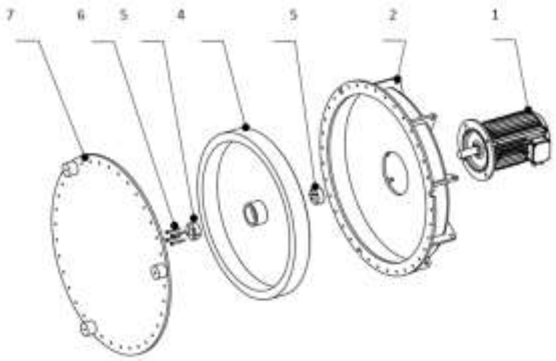

Fig. 1. Exploded view of the preexisting stand

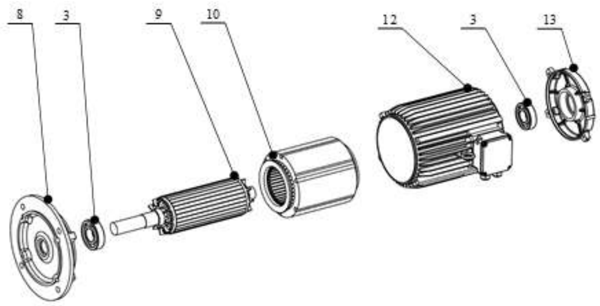

Fig. 2. Exploded view of the Radial Asynchronous Induction Electrical Machine

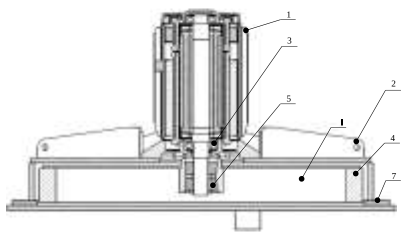

Fig. 3. Half section of preexisting stand

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The construction of the radial flux asynchronous electrical machine shown as pos. 1 has new bearings (pos. 3) that come with reduced frictional losses. Additionally, the radial asynchronous machine has 2 poles with a synchronous speed of 3000 rpm and 22 kW of power.

A vacuum pump is connected to the hermetically sealed welded housing that creates a vacuum in the surrounding volume of the kinetic accumulator. Thus it minimizes the aerodynamic friction losses during when the flywheel is spinning. The whole construction is mounted onto a space frame with added panels for inspection.

The preexisting test bed is shown on Fig. 4.

Fig. 4. Preexisting test bed

III. Novelty Design of Axial Flux Induction Electrical Machine

The novelty of the design consists of the way the stator and rotor cores are created as well as the coil cores for the rotor cage and stator coils.

- The main part of the stator created from a spirally wounded sheet of electrical grade steel with a length enough for the desired inner and outer diameters of the rotor and stator.
- The main part of the rotor is created from a single solid metal disk with a desired thickness or from a spirally wounded sheet of electrical grade steel.
- The magnetic cores of the squirrel cage of the rotor and the magnetic cores for the stator coils are created from laminated electrical steel, stacked up to the desired height for the motor.

These modifications are shown on fig. 5 for the stator and on fig. 6 for the rotor.

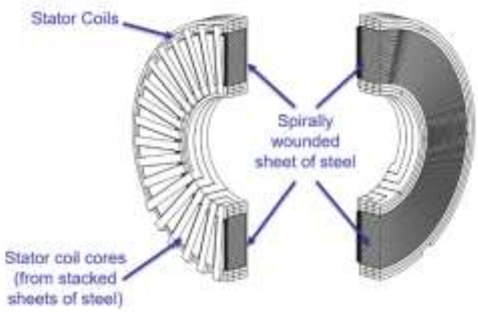

Fig. 5. Half section of the stator of a novelty axial flux asynchronous electrical machine.

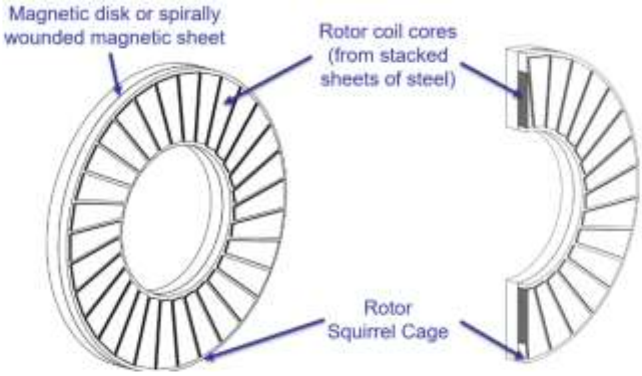

Fig. 6. Rotor construction of a novelty axial flux asynchronous electrical machine.

Fig 5. shows the stator construction in a half section. Shown on the figure is the tightly spirally wounded sheet of electrical steel that forms the main part of the magnetic core of the stator as well as showing that the magnetic cores for the stator are manufactured from stacked sheets of electrical steel. Thus the construction of the stator is simplified and made cheaper because the need for a cutting die which is expensive to manufacture. The only tool needed to create the bulk of the stator is a hand shear cutting machine. Additionally, the stator coils are wounded around these magnetic cores.

Fig 6. shows the rotor construction in a half section. Shown on the figure is the tightly spirally wounded sheet of electrical steel that forms the main part of the magnetic core of the rotor or a magnetic disk. As with the stator, the magnetic cores that are formed between the squirrel cage are manufactured from stacked sheets of electrical steel. Additionally, the squirrel cage of the rotor is created by casting of copper or aluminum.

The similar construction and principle of work of the axial electrical machine is close to that of a radial asynchronous one thus the machine can be classified as an Axial Asynchronous Electrical Machine. [3]

IV. Novelty Axial Flux Asynchronous Electrical Machine – Virtual Prototyping and Modelling with Finite Element Methods

Virtual prototyping mainly consists in the use of computer modeling using Finite Element Methods and followed by simulation and design. Thus the prototyping process is reduced significantly to physical prototyping and can predict dynamic and other hard to determine in the physical world characteristics of the prototype. [4] [5]

A Finite Element Model of the Novelty Axial Flux Asynchronous Electric Machine is shown in Figure 7. The model is created as a 3-dimensional (3D) mesh model with a plane of symmetry in order to create a half-model thus reducing the calculating time. A 2D Finite Element Model can significantly accelerate the calculating time but axial flux machines are not able to be modeled as such.

The axial flux electrical machine has 6-poles and a synchronous speed of 1000 rpm. The modeled elements of the machine are a stator (pos. 1) and a rotor (pos. 3) made of electrical steel, stator coils (pos. 2) made of copper and a squirrel cage, made of cast aluminum.

The modeled FEA model has an inner diameter of the rotor and stator of 140 mm, an outer diameter of 355 mm and a total height of the electrical machine of 117 mm (with a 2 mm air gap between the rotor and stator).

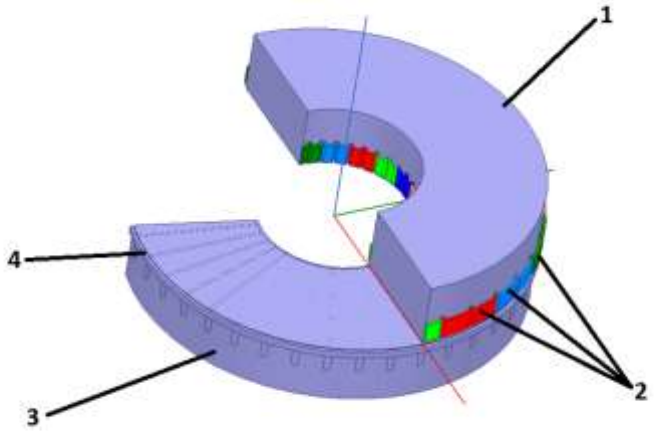

Fig. 7. FEM model of a novelty axial flux asynchronous electrical machine

The boundary conditions of the given electrical machine are the definition of the windings for the individual phases of the stator and rotor speed. The definition of the stator coils is shown on fig. 8 with shown in red – Phase A, shown in green – Phase B and shown with blue – Phase C.

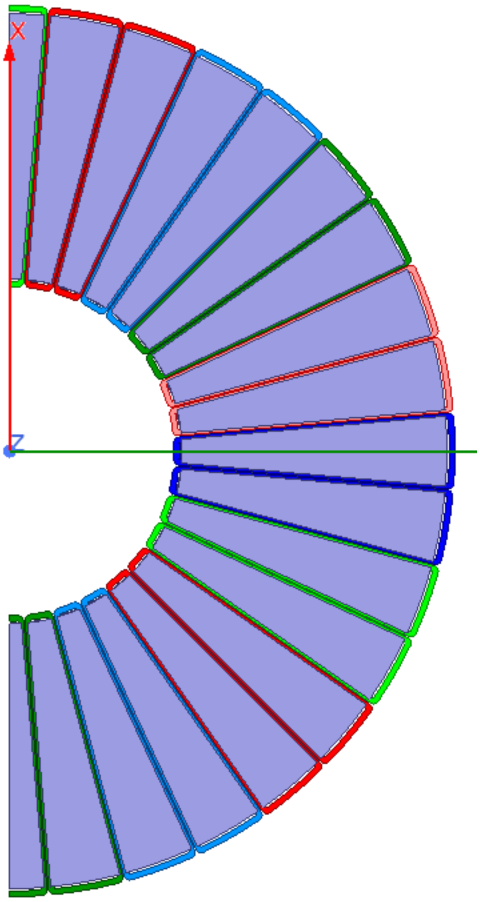

Fig. 8. Boundary conditions for an axial flux asynchronous electrical machine (Red – Phase A, Green – Phase B, Blue – Phase C)

The shown boundary conditions on Fig. 7 are supplemented by assigning the rotor speed to the rotating domain of the finite element model. The set speed is 2895 rpm. The electrical circuit which is powering the machine is shown on fig. 9. The frequency of the alternating current is set to 150 Hz (simulating the function of the Variable Frequency Device – VFD).

The shown machine has a stator with 36 coils and 6 poles and a rotor that has 40 rotor bars.

The poles and the rotor bar count were determined in order to minimize ripple torque. The lowest pole count for an axial flux machine is determined to be 4-pole and increasing it minimizing the ripple torque thus a 6-pole machine was modeled. The reason the rotor bars are 40 is that for the given stator coil and rotor combination no additional skew angle of the rotor bars is needed to minimize the said ripple torque.

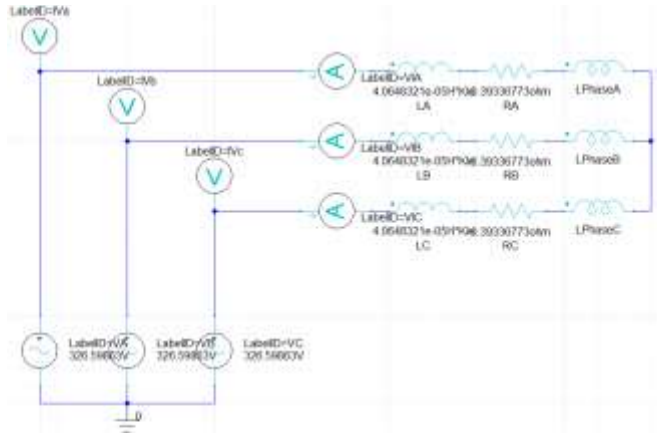

Fig. 9. Electrical circuit for a novelty axial flux asynchronous electrical machine.

V. RESULTS FROM THE FINITE ELEMENT MODEL CALCULATION OF A NOVELTY AXIAL FLUX ASYNCHRONOUS ELECTRICAL MACHINE

The results from the Virtual Prototype are presented in three different aspects – Induced Voltage in the stator, Stator Currents, Torque, Electrical Power and Mechanical Power, as well as the magnetic flux in the finite element model.

A. Phase Voltage Induced in the Stator Windings

The induced voltage in the phase windings is up to 310V with a sinusoidal form as shown in fig. 10.

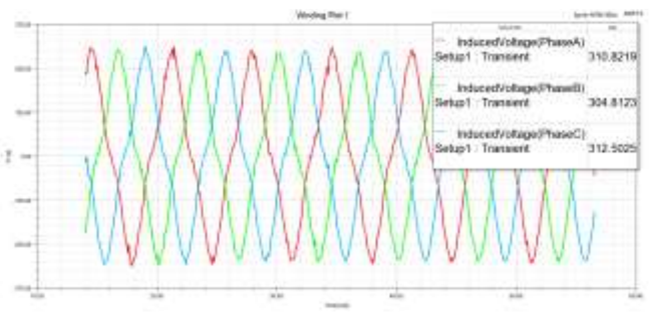

Fig. 10. Phase Voltage Induced in the Stator Windings of a Novelty Axial Flux Asynchronous Electrical Machine

B. Stator Current

The stator current in the phase windings is up to 380 A after stabilizing with a sinusoidal form as shown in fig. 11.

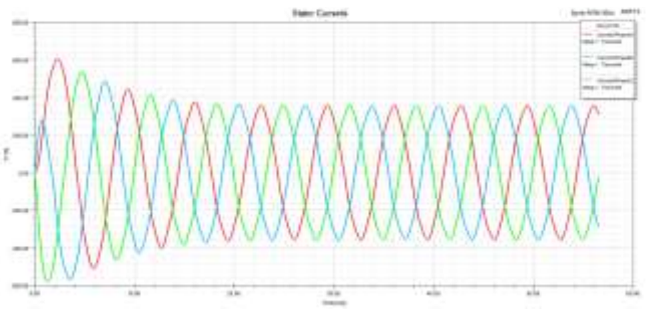

Fig. 11. Stator Windings Current of a Novelty Axial Flux Asynchronous Electrical Machine

C. Generated Torque

The generated torque of the modeled machine working as a motor after stabilizing of the solution has a maximum of 90.4 Nm and average of 82-85 Nm. This generated torque is shown on Fig. 12.

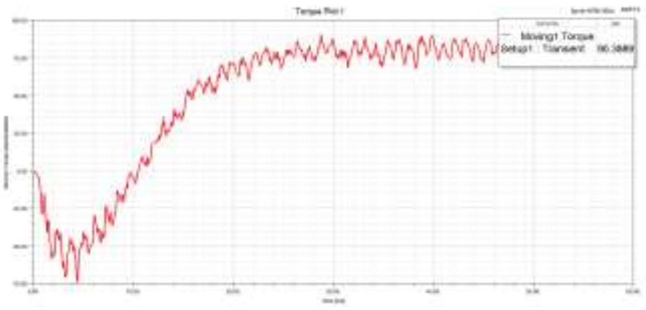

Fig. 12. Generated torque of a Novelty Axial Flux Asynchronous Electrical Machine

D. Generated Electrical Power

The generated electrical power of the electrical machine after stabilizing of the solution is around 29.2 kW. This power is shown on Fig. 13.

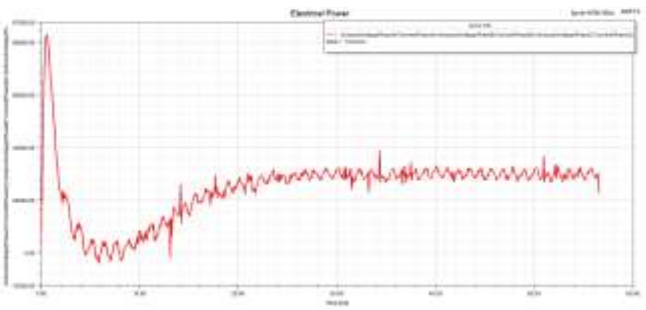

Fig. 13. Generated Electrical Power of a Novelty Axial Flux Asynchronous Electrical Machine

E. Generated Mechanical Power

The generated mechanical power of the electrical machine after stabilizing of the solution is around 24.15 kW. This power is shown on Fig. 14.

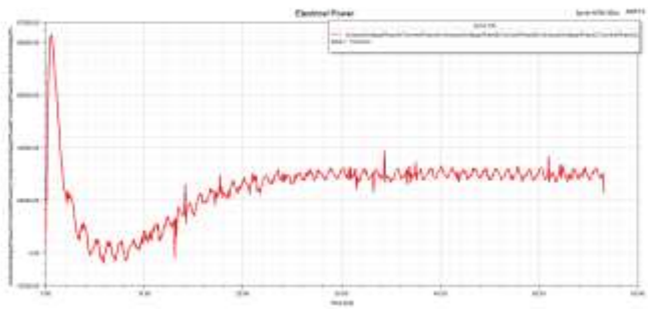

Fig. 14. Generated Mechanical Power of a Novelty Axial Flux Asynchronous Electrical Machine

F. Magnetic Flux

The magnetic flux distribution is important in order to determine the magnetic lines pats. On fig. 15 and fig. 16 magnetic flux distribution is shown both stator and rotor. The Magnetic flux distribution has a peak of 3.8 T (higher quality mesh will lower it to the average of 2.5 T for the model).

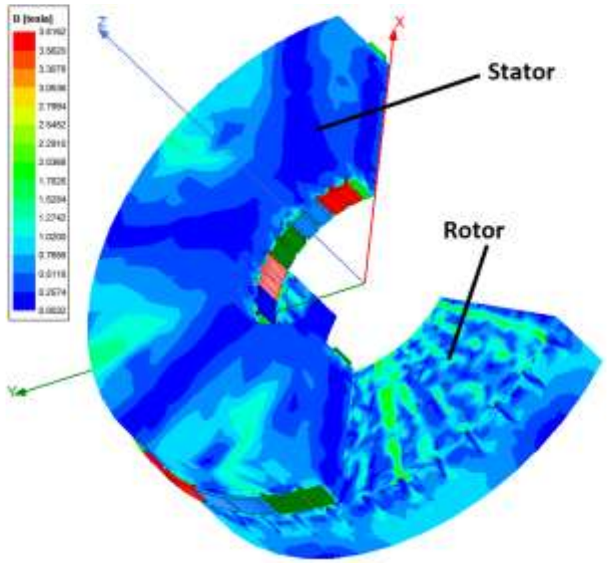

Fig. 15. Magnetic flux of a novelty axial flux asynchronous electrical machine viewed from the rotor side.

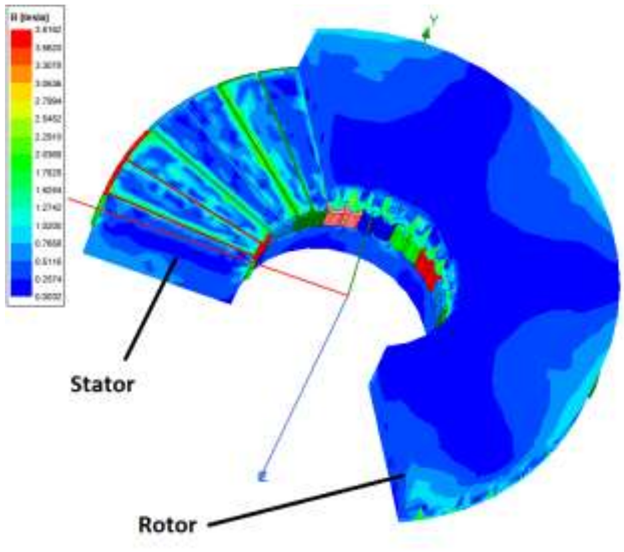

Fig. 16. Magnetic flux of a novelty axial flux asynchronous electrical machine viewed from the stator side.

VI. Conclusion

Based on the research, the following conclusions were made:

- Axial Flux Induction Electrical Machines have the benefit of being cheaper to produce than their PM axial alternatives.
- Axial Flux Electrical Machines have the property of having high mechanical characteristics (power and torque) relative to their volume.
- The novelty of the suggested design ensures that no special cutting dies are needed for the creation of the electrical machine thus lowering its manufacturing cost significantly.
- The FEA model that is created shows high mechanical parameters based on the given working parameters (2895 RPM @ 150 Hz)
- The calculated efficiency is around 83% which as acceptable being that a radial asynchronous electrical machine with 30 kW and IE1 efficiency is around 88%-90%.
- Additional increase in efficiency can be gathered by lowering the air gap.

Based on the research a physical prototype of an axial flux induction electrical machine with the novelty design is being constructed in order to validate the differences the novelty construction will introduce to the working parameters of the machine.

Acknowledgment

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References

[1] M. Subkhan and M. Komori, "New concept for flywheel energy storage system using SMB and PMB," *Applied Superconductivity, IEEE Transactions,* no. 21, pp. 1485 - 1488, 2011.

[2] T. Aanstoos, J. P. Kajs, W. Brinkman, H. P. Liu, A. Ouroua and R. J. Hayes, "High voltage stator for a flywheel energy storage system," *IEEE Trans. Magazine,* vol. 37, no. 1, pp. 242-247, 2015.

[3] A. Hughes and B. Drury, Electric Motors and Drives (Fifth Edition), 2019.

[4] В. Гълъбов, Я. Софронов and А. Милев, "Определяне на предавателните функции на механизми за ориентация на крайния ефектор на шестзвенни Q-манипулатори," *Механика на машините,* no. №97, pp. 15-19, 2012.

[5] В. Гълъбов, Я. Софронов and А. Милев, "Синтез на основния механизъм на робот екстрактор на отливки," *Механика на машините,* no. №97, pp. 3-8, 2012.