AN INNOVATIVE TECHNOLOGY FOR PRODUCTION OF AXIAL INDUCTION MOTOR

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Abstract: This study presents the latest technology to produce axial induction motors for application in electric vehicles. A review of current state-of-the-art technology is performed on the solutions with soft magnetic powder core or machined parts that are not appropriate for mass production. Therefore, new technology is proposed, based on analyzed production technologies specifics. It involves use of a standard metal strips to make both stator and rotor cores. This design includes a spirally wound strip of magnetically conductive material and stacked trapezoidal lamellas. The trapezoidal lamellae are cut using waste-free technology for e.g., guillotine, without specialized punches as in traditional engines. As a result, metal cutting operations are significantly simplified and require widely used production equipment in the industry. The developed technology is appropriate for mass production due to its relatively low cost and eases adaptability. The proposed design is at the physical prototyping and testing stage. Thus, it will be validated by testing the physical prototype in the real industrial environment. This innovative technology is patented and currently under commercialization.

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Keywords: Technology, Innovation, Axial, Induction, Motor.

Introduction

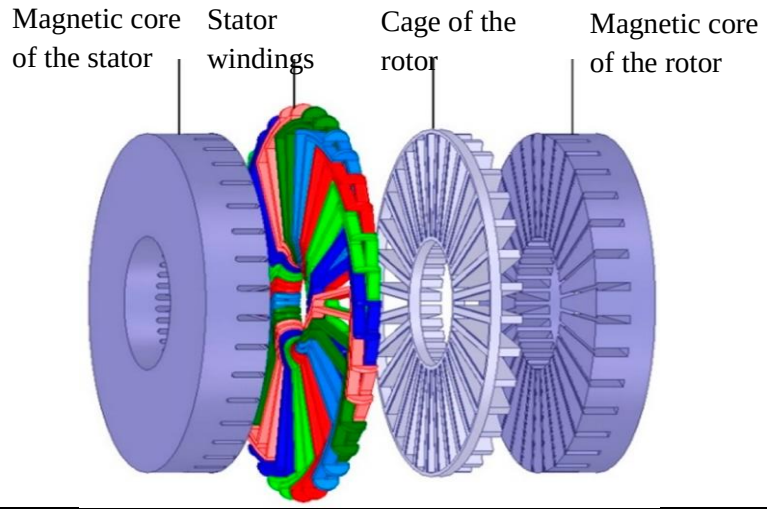
Electric vehicles (EVs) and hybrid vehicles (HEVs) have been identified as the most viable solutions to address environmental issues. Electric drives play a key role in such vehicles and have developed significantly in recent years. The development of new materials for permanent magnets has led to several new designs based on new geometric topologies and control strategies. Thus, brushless permanent magnet drives have been identified as promising with all the characteristics mentioned earlier for modern electric and hybrid cars. However, permanent magnets add their share to electric drive costs. Therefore, it leads to the development of other cost effective designs using an induction motor that does not have permanent magnets. Radically developed induction motors with cage rotors are the widely used designs. These motor types are appropriate for industrial application, but because of their overall dimensions and shape (cylindrical), they are unsuitable for EVs, where axial size is of great importance. Motor types developed axially with the same principle have great potential in EVs (Ashari, et al., 2014).

Axial Flux Induction Motor (AFIM) is a variant of the radial type, where the air gap between the rotor and the stator is in the axial direction, while the windings are located radially. Another specific feature of this design is that the axial dimension is smaller than the radial, i.e., both stator and rotor are discs. (Nasiri-Gheidari & Lesani, 2012) (Patterson, et al., 2009). However, AFIM design specifics have production difficulties especially connected to their cores resulting in relatively high production costs (Kubzdela & Weglinski, 1988) (Varga, 1986). Additional problems are connected to the applied dynamic loads: peripheral velocity and axial force acting over bearings (Dianati, Kahourzade, & Mahmoudi, 2019).

A schematic diagram of this type of motor is illustrated in Figure 1, displaying its single-sided subtype (Arabul, Senol, & Oner, 2020). The stator consists of a magnetic core and windings located in the radial channels are connected according to a certain scheme. The rotor's magnetic core also has radially arranged channels in which an alloy (usually aluminum) is casted, which acts as a cage (short-circuited rotor). An important factor in asynchronous motors is the size of the air gap (Hecker, Igelspacher, & Herzog, 2010). The goal is to keep it to a minimum, which seriously increases the output parameters of the engine and especially its efficiency (De Almeida, Ferreira, & Baoming, 2014).

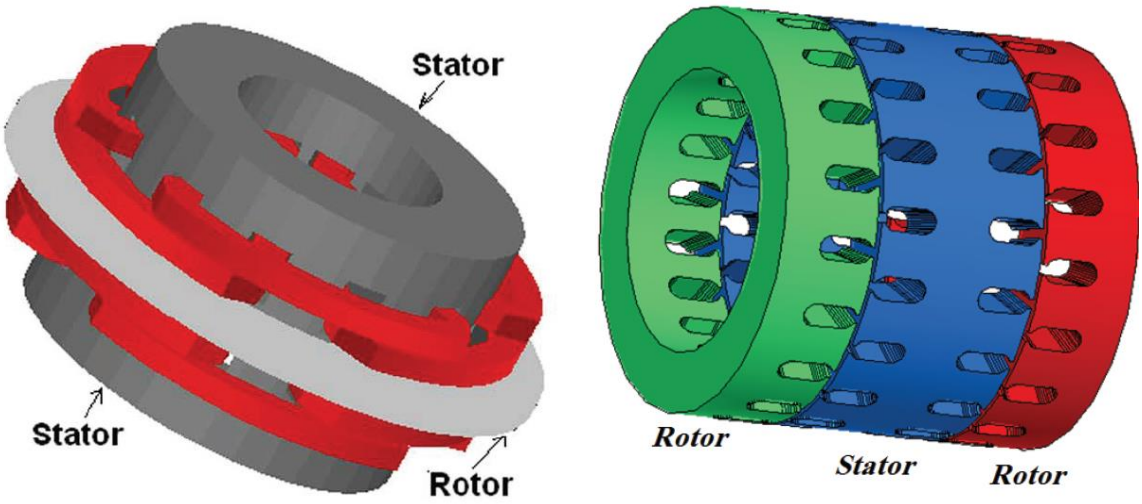
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Figure 1: Single-sided AFIM components



Source: Arabul et al., 2020

Figure 2: Different configurations of double-sided of AFIMs



Source: Nasiri-Gheidari & Lesani, 2012

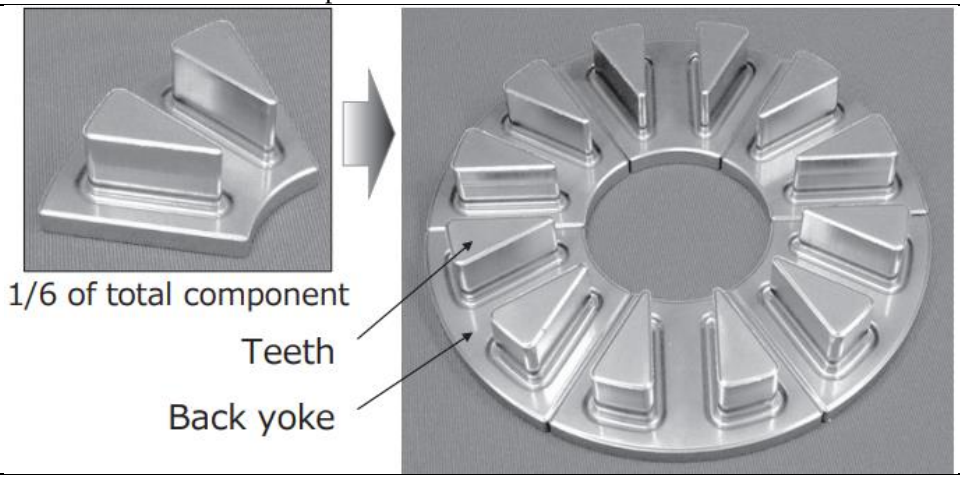
AFIM is suitable to be stacked in series if the rotor is double-sided and two stators are used. Another option is to use a single stator and two rotors. Such design solutions are shown in Figure 2 for both types mentioned before (Mirzaeiahi, Mirsalim, & Abdoll, 2007). Another important option is to stack several AFIMs in a package. This solution is viable for energy storage systems in kinetic energy recuperation systems (KERS) using AFIM in both motor and generator modes.

State-of-the art of production technologies

Radial flux induction motors are manufactured in series with well-established and widely used production technologies for industrial applications. The magnetic core of both stator and rotor are produced by stacking sheet metal components. These sheet metal components are suitable for mass production as punching tools produce scrap. This widely used production technology is very effective, but scraps quantity, reduces its economic effectiveness, especially for stator production.

This production technology is not directly used in axial flux induction motors, especially for stator manufacturing. Axial stator requires forming radially oriented channels, which could not be achieved effectively by stacking lamellas. Various production solutions are available currently. Some use soft magnetic powder core (SMPC) components to form stator core assembly, as shown in Figure 3. (Watanabe, Saito, Ueno, Tsuruta, & Nakamura, 2018). Other designs use entirely machined single-piece cores.

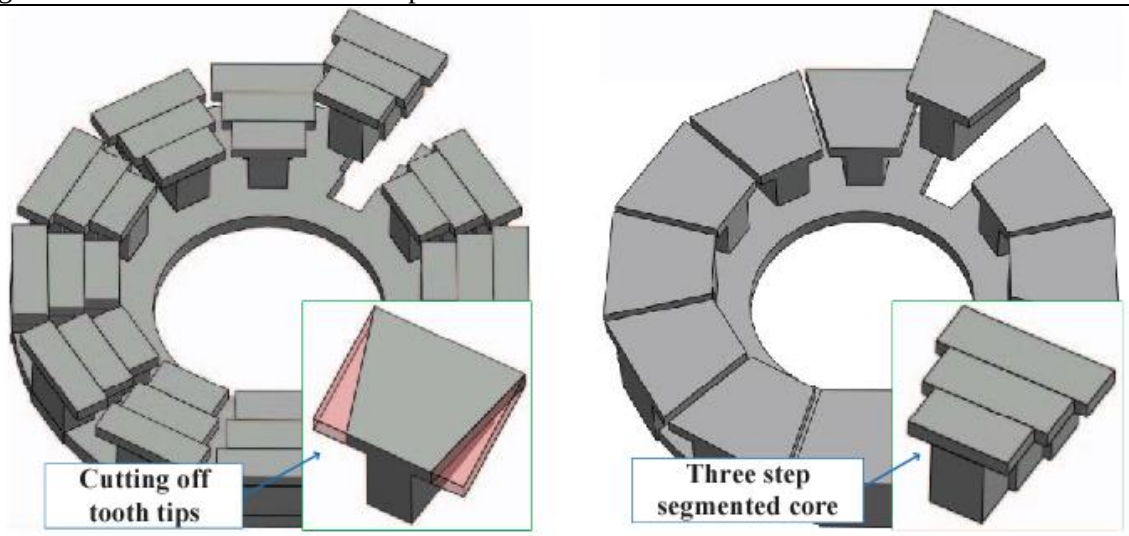
Figure 3: AFIM stator of SMPC components



Source: Watanabe et al., 2018

Some design types also use machined parts to build assembled structure for the stator's magnetic core, as shown in figure 4. This approach aims to simplify winding and fastening manufacturing speed using the segmented core of the stator. However, its cost (per unit) increases due to cutting off the tooth tip to the constant slot width. Proposed solution aims to decrease the cost by using assembled components (Kim, Jeon, Byun, & Cho , 2015).

Figure 4: AFIM stator of SMPC components



Source: Kim et al., 2015

It can be stated that most of the used technologies are suitable for prototyping and are expensive for mass production. It is a basis for new technology development. It needs to propose cost effective solutions for mass production. Despite design concept advantages, its production cost could be a decisive factor for its implementation in today's economically efficient industry. Another important option is regarding the possibilities for easy development of different size ranges for successive product generation (Malakov, Zaharinov, & Tzenov, 2015)

New production technology development

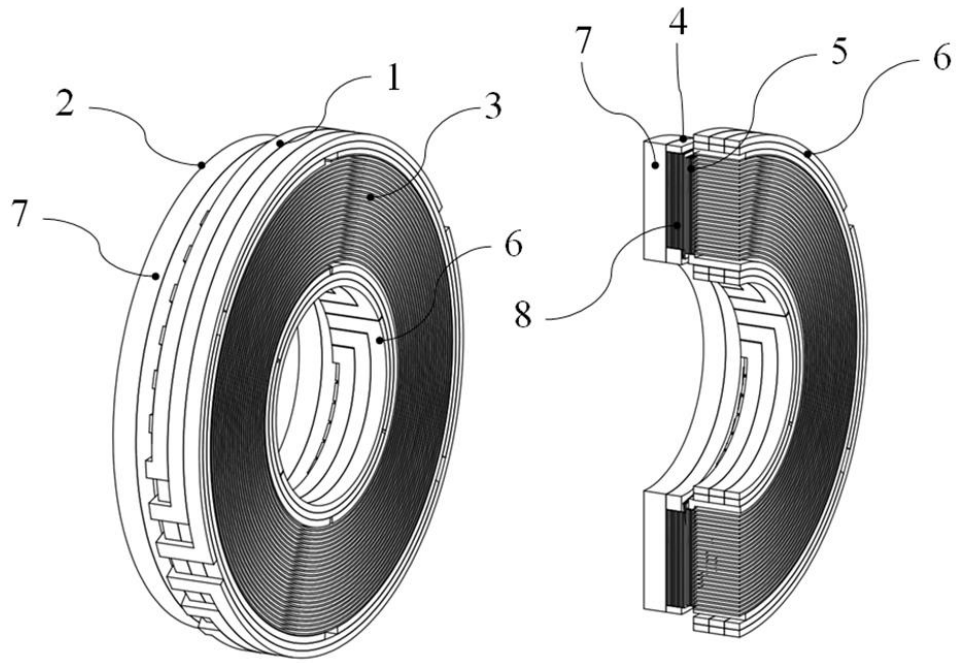
There are two starting directions for developing new production technology for axial flux induction motor cores (stator and rotor): technological requirements and design solutions (Ivanov, Kamberov, & Zlatev, 2020).

Production technology requirements

The objective is to create an innovative design of axial induction motor that allows its production without specialized tooling by maintaining a low cost of production and high machine efficiency.

It is achieved by creating the design of an electric motor, using easy-to-make blanks for producing the stator and the rotor and universal machines with a minimum waste. Accordingly, the developed AFIM has a stator with stator windings and a stator core holding a spirally wound strip of magnetically conductive material with a winding axis coinciding with the machine's rotation axis. Magnetically conductive sheets with axial orientation are mounted on the wound stator core in the form of trapezoidal lamellae, which act as a core for the stator windings. The shape of these lamellae should be designed in such a way that they can be safely made from the tape on universal machines without specialized punches. The stator windings can be pre-wound by machine and placed around the already built cores with minimal effort. The number of poles of the stator of the AFIM should always be an even number.

Figure 5: General view of proposed innovative design



Source: Authors

Similarly, the rotor is a disk of magnetically conductive material mounted on a motor shaft. As for the stator core, trapezoidal lamellae made of magnetically conductive material are arranged in stacks on the disk surface, and thus mounted, surrounded by a rotor cage. These stacked rotor lamellas are made of a material with low magnetic and high electrical conductivity, specialized aluminum or copper alloys. The lamellas have a quadrangular shape with straight sides, thus providing the desired slope in the cage without the complex shapes of the lamella cores. The shape of these lamellas used for the stator core, is waste-free and made of tape with universal machines, without specialized punches.

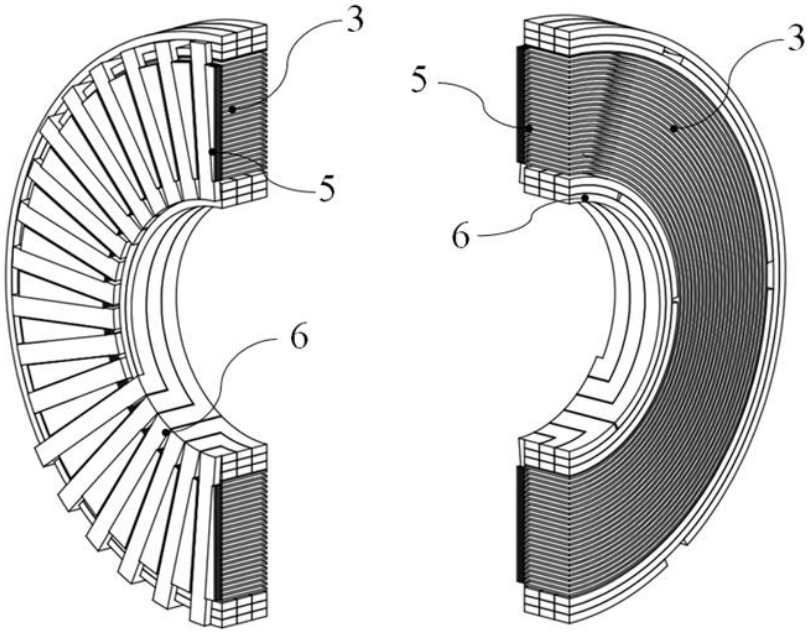
Design solution

The axial flux induction motor design is shown in Figure 5, which consists of a stator 1, a core 3, and a spirally wound strip of magnetically conductive material with a winding axis coinciding with the axis of rotation of the electric machine. The initial workpiece is a standard metal strip; further, this solution requires a conventional technology that uses an instance turning machine to produce the spiral. Next, spiral ends are fixed by welding. These processes are inexpensive and do not require special technical equipment, which is a key factor for successful design.

Lamellas 5 which are trapezoidal (have four straight walls, at least two of which are parallel) are stacked (stacked on top of each other) on the spirally wound strip of the core 3 of the stator 1. These are made of sheets of magnetically conductive material and mounted together with traditional engineering means, for example, by welding, soldering, and fastening or by using screws. These stacks of sheet metal components 5 have an axial orientation and play the role of a core for the stator windings 6. The shape of these lamellae to be safely made of tape on universal machines, without specialized punches, as is stated in the technical requirements.

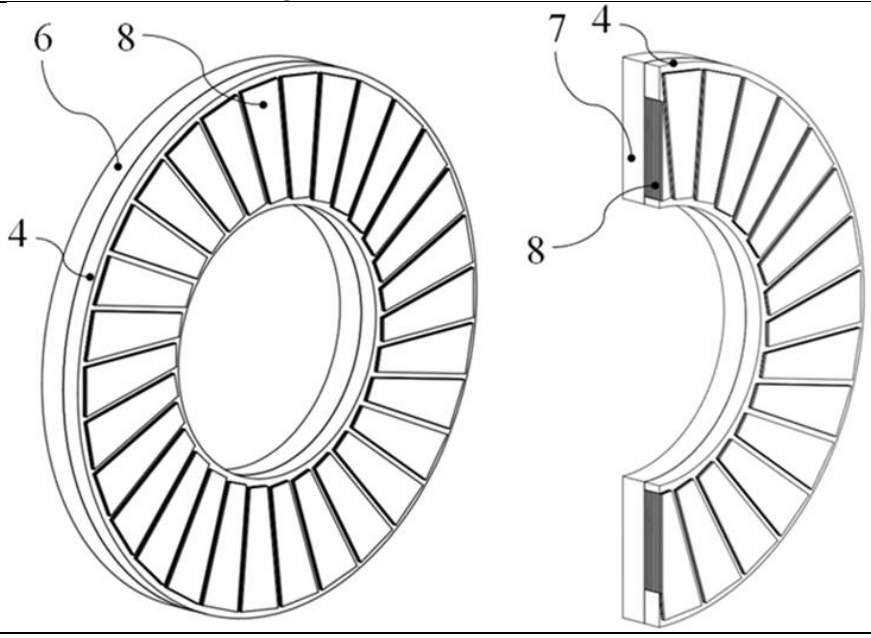
Figure 6 illustrates the detailed design of the stator. The stator windings 6 themselves can be pre-wound by machine and placed around the already built core 3 with stacked lamellas. This is a conventional approach, and it is used in industry. These windings are organized according to a predefined scheme that depends on the number of poles. This design solution has 36 slots (6x7.5mm section) for windings, following a scheme of 3 slots forming a pole and a sequence of +A/-C/+B/-A/+C/-B. Traditional lamella packages (for radial flux induction motors) consist of several discs that are stacked, and depending on the diameter of the electric motor, punches are required for discs of different diameters. At the same time, the innovative design described here requires only one strip, which is wounded to different diameters.

Figure 6: Detailed view of stator design (Windings schematics)



Source: Authors

Figure 7: Detailed view of rotor design



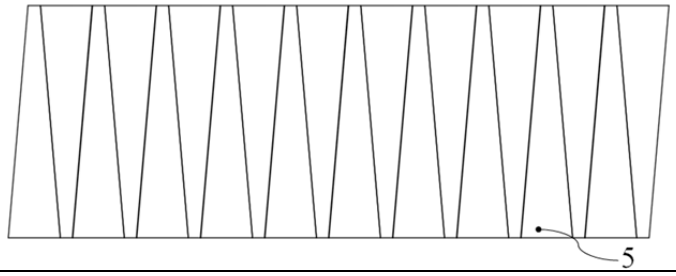
Source: Authors

The rotor of the innovative AFIM design, shown in Figure 7, consists of disk 7 of magnetically conductive material, which is mounted to the motor shaft. Lamellas 8 that form stacks are radially arranged on disk 7. The lamellas 8 are also made of magnetically conductive material and have the

shape of a trapezoid (with two parallel walls), allowing waste-free fabric production of universal machines without specialized punches. The stacked lamellas 8 of rotor 2 are surrounded by a rotor cage 4, which is made of a material with low magnetic and high electrical conductivity, for example aluminum or copper alloys.

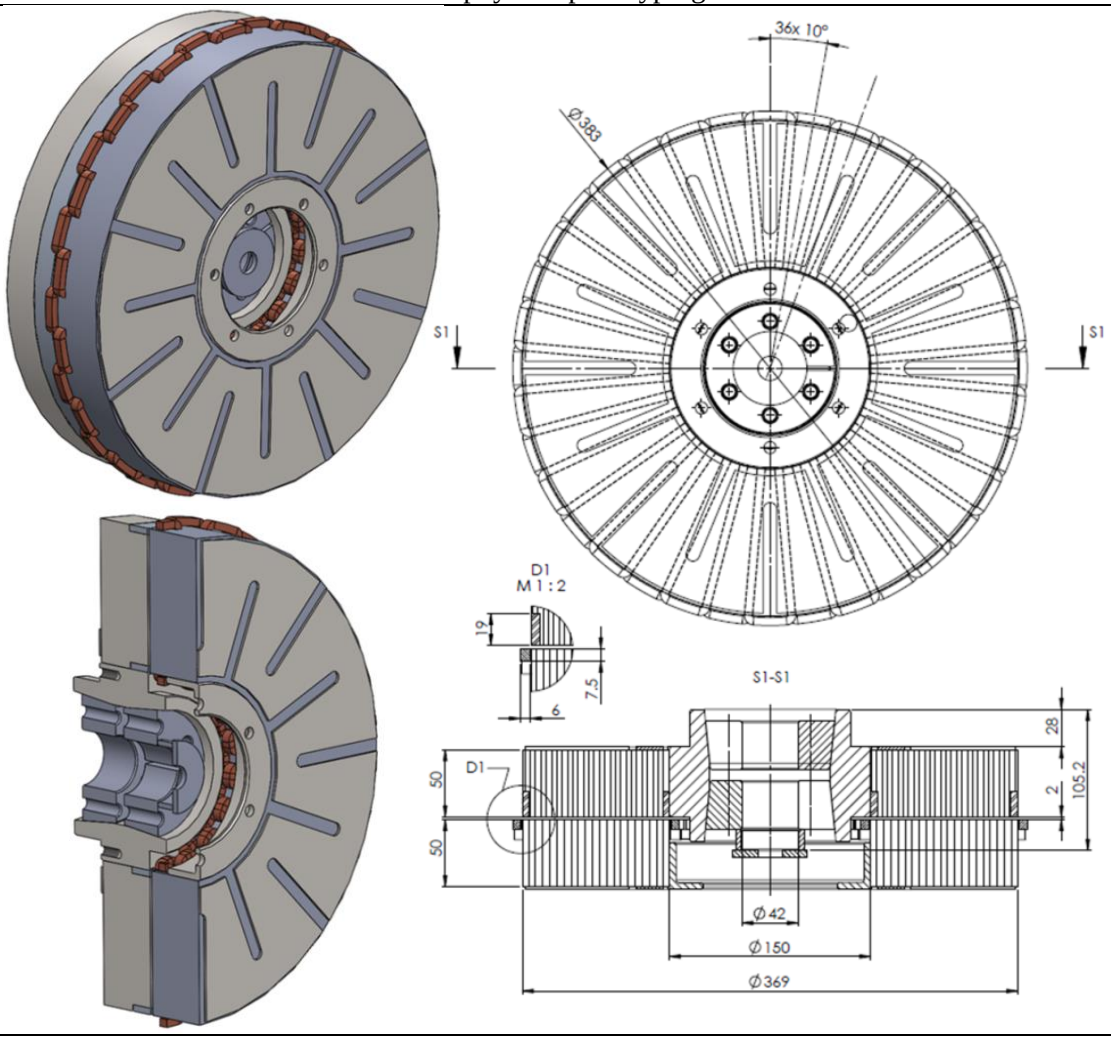
The trapezoidal lamellae 5 can be cut, as shown in Figure 8. In this way, waste-free technology is used for cutting, for example, on a guillotine, without specialized punches as in traditional engines.

Figure 8: Lamellas production using band workpiece



Source: Authors

Figure 9: 3D model and documentation for physical prototyping



Source: Authors

The proposed innovative design of AFIM is prepared for prototyping. Its general design view and major dimensions are shown in Figure 9.

Conclusion

Innovative production technology for axial flux induction motors is developed and demonstrated. Its main advantage lies in using standard workpieces: sheet metal bands for producing stator and rotor

cores. This technology does not require a specialized punching tool and involves universal cutting machines to produce lamellas for manufacturing stators and rotors. Production cost is also reduced also as less scrap is generated during the production process.

The proposed design is at the stage of physical prototype manufacturing (Figure 9) and testing.

Acknowledgement

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