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UKŁADY NAPĘDOWE STOSOWANE W POJAZDACH ELEKTRYCZNYCH

Streszczenie: Artykuł dotyczy układu napędowego i silników elektrycznych stosowanych we współczesnych nowoczesnych pojazdach elektrycznych. We wstępnej części artykułu w skrócie omówiono przyczyny wprowadzenia elektromobilności oraz pokrótce opisano najczęściej używane silniki elektryczne i ich główne wymagania. Celem artykułu jest skupienie się na poszczególnych rodzajach silników elektrycznych, opisanie różnych koncepcji silników elektrycznych oraz wskazanie ich zalet i wad. Wreszcie, artykuł skupia się na zintegrowanych napędach elektrycznych stosowanych we współczesnych nowoczesnych pojazdach elektrycznych. Efektem jest porównanie, ocena problemu i możliwych perspektyw na przyszłość.

Słowa kluczowe: silnik elektryczny, zintegrowany napęd elektryczny

PROPULSION SYSTEMS USED IN ELECTRIC VEHICLES

Summary: The paper deals with the drive system and electric motors, which are used in modern electric vehicles. The first part of the article briefly deals with the reasons why electromobility is popular nowadays and describes the most used electric motors. The aim of this article focuses on individual types of electric motors, describes various concepts and specifies their advantages and disadvantages. In the final part, the paper defines integrated electric drives used in today's modern electric vehicles. The output is a comparison, evaluation of the issue and possible prospects for the future.

Keywords: electric motor, integrated electric drive

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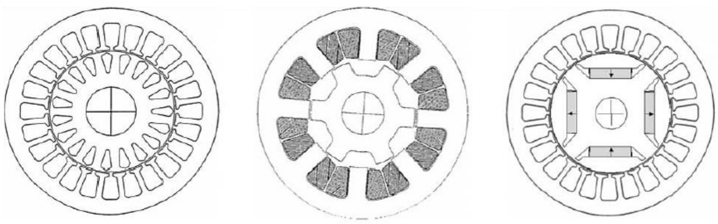
1. Introduction

In the last ten years, car manufacturers, under pressure from the public, have become increasingly inclined to alternative energy sources, such as electric propulsion. The popularity of electric vehicles (EVs) is gradually increasing, not only due to efforts to reduce harmful emissions into the air but mainly due to reducing dependence on fossil energy sources. Every year new and new models are manufactured, new companies arise that are dealing with the development and manufacturers of EVs. These are clearly interesting technologies, but they still suffer from many shortcomings, such as an unreasonably short driving range, a high purchase price and an insufficient number of charging stations significantly slowing down their expansion. Especially for these reasons, the number of EVs in Slovakia and the Czech Republic is minimal. On the other hand, they have several benefits that not all ordinary people know about. Their clear advantages include low operating costs, quiet running, good torque and more. There are several hundred pieces of EVs, so meeting an EV in the region is currently a relatively rare phenomenon. It is obvious that EVs today, despite state subsidies, are expensive and luxurious affairs.

2. Electric motors

EVs consist of four basic parts: electric motor, regulator, batteries and battery charging system. An electric motor is an electrical device that, unlike a conventional internal combustion engine, uses electromagnetic phenomena to create mechanical motion. The great advantage of the electric motor is the fact that it is a very simple device, which consists of only two mutually integrating elements. These elements are the stator and the rotor. Another advantage of the electric motor is its feature that its behaviour resembles a generator, which means the possibility of recuperation. The recuperation principle is applied during braking and decelerating the vehicle and allows the energy to be returned to the battery, resp. to be recharged. The main feature of the electric motor in automobiles is the ability to achieve maximum torque from almost zero speed and, thanks to the large operating speed range, the need for a conventional multi-speed transmission, which is replaced by a reducer. Electric motors can be divided into several categories according to the type of current supplied into direct current and alternating current. AC motors are further divided into synchronous and asynchronous (induction).



(a) (b) (c)

Figure 1. Most used electric motors (a) induction motor (b) reluctance motor (c) synchronous motor with permanent magnets

Among the most popular motors (Figure 1) are permanent magnet motors, which dominate with their properties. The problem with this type of motor occurs in the limited number of rare permanent magnets. The solution seems to be induction and reluctance motors, which do not contain permanent magnets and they are currently the most developed.

Main requirements of electric motors:

- high instantaneous and specific power,
- high torque even at low speeds,
- fast onset of performance,
- high reliability and efficiency,
- favorable price.

Synchronous motors are most often used in combination with permanent magnets (PMSM), which are located either on the surface or inside the rotor (Figure 2). Magnets used in synchronous motors are mostly neodymium. These motors, as the name suggests, are characteristic of the synchronous movement of the rotor and stator. The magnetless design includes a rotor with an excitation winding that requires a constant current supply to create a magnetic field. The stator consists of sheets and in their grooves is located a three-phase winding which produces a magnetic field under alternating voltage. A rotating magnetic field is created in the stator with the help of an alternating current. The constant magnetic field of the rotor caused by the permanent magnets integrates with the induced field of the stator and thus the motor rotates. For starting this type of engine is often used starting cage, which is the main part of induction motors.

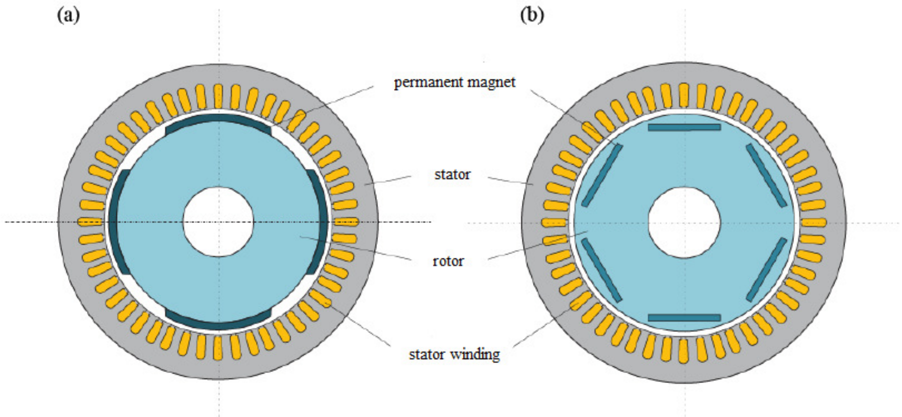


Figure 2. Cross section of motors with permanent magnets (various magnet bearings) (a) permanent magnets on the rotor surface, (b) permanent magnets inside the rotor

Advantages of PMSM:
- The rotor does not require a power supply.
- High specific power thanks to strong magnets.
- Low noise and vibration.
- More powerful than induction motor.

Disadvantages of PMSM:
- High price of magnets.
- Sensitive to working temperature.

The asynchronous (induction) motor was invented in 1882 by Nikola Tesla and it is the most widely used electric motor in all areas of industry. Its popularity is due to the fact that it is possible to supply this motor with the alternating current without a converter and thus deliver a constant speed. In an EV, a converter is used to change the speed. This type of motor consists of a stator with a three-phase winding and a cage-shaped rotor (Figure 3). A rotating magnetic field is generated in the stator by means of an alternating three-phase current, which induces a current on the closed rotor cage. This induced current causes a magnetic flux in the rotor, which integrates with the stator and causes the desired rotation of the rotor. However, this rotation can never equal the rotational speed of the magnetic field in the stator.

Figure 3. Audi three-phase asynchronous motor

Advantages:

- High reliability and low price.
- Minimum maintenance requirements.

Disadvantages:

- Small speed range.
- Low starting torqu.

Another promising candidate for use in EVs is the switched reluctance motor (SRM). As the name suggests, it uses magnetic resistance - reluctance. Despite the great potential of this type of motor, it has not been used in the past due to its complexity when controlled by frequency converters. Just these properties make the reluctance motor a suitable candidate for use in electric vehicles. On the contrary, the main disadvantages include higher noise and the need to use electronics to monitor the position of the rotor. Another disadvantage is the use of a converter for the correct supply of the winding on the stator. Unlike the conventional synchronous version of this motor, the SRM has poles on both the rotor and the stator. The stator carries a winding at each pole, while the rotor is without any winding or permanent magnets. A magnetic field is generated on the rotor when current is applied to the corresponding stator poles. Subsequently, the rotor tries to get to a place with the lowest possible magnetic resistance and it starts to spin. Next, the current is sent to the other poles on the stator and this process is repeated. The number of poles on the rotor is usually smaller than on the stator (Figure 4) to prevent the dead center, i.e. position at which the motor would have no torque.

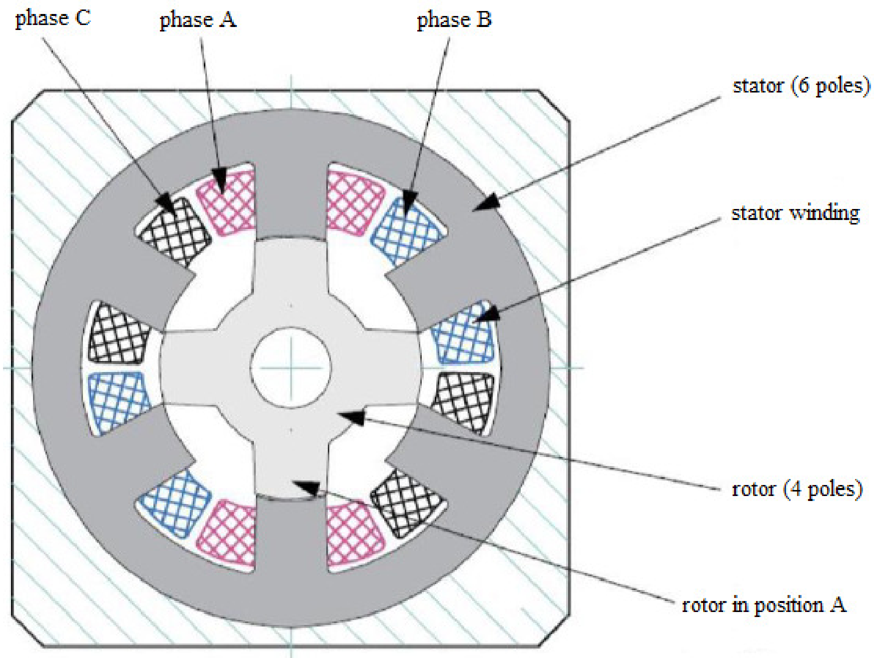


Figure 4. Scheme of reluctance motor

Advantages of the reluctance motor:
- Simple construction.
- Low production costs.
- High specific power.
- Efficiency up to 95%.
- Wide speed range.

Disadvantages of reluctance motor:
- Higher noise.
- Complex management.
- Prize.

3. Integrated electric drives

E-axle (electric axle) is a compact and cost-effective electric drive solution for electric vehicles and hybrid applications. The electric motor, power electronics and gearbox are combined in a compact unit that directly drives the vehicle's axle. This helps make electric drives less complex and simpler. In addition, the drive unit becomes cheaper, more compact and more efficient. The main advantages of these compact power units include affordable price, low weight and versatility for various applications. GKN, which was the first in 2014 to start series production in cooperation with BMW, became a pioneer in the development of this technology. It was BMW that used their E-axle in the BMW i8 hybrid car. This solution is very attractive for car manufacturers due to the easy installation of the E-axle and the ability to rework existing models into electrical versions. The latest product from GKN (Figure 5) is the E-axle eTwinsterX, which has a two-speed coaxial gearbox, the synchronous motor with permanent magnets, differential and two clutches. This system was introduced in collaboration with the Jeep Company on the Renegade model. Gear ratios are 17 and 9.5, electric motor power is 120 kW, torque up to 3,500 Nm and maximum speed 18,000 rpm. The GKN brand and its E-axle versions can be found, for example, in BMW, Volvo or Porsche cars.

Figure 5. E–axle GKN eTwinsterX

Another strong player in the field of electromobility is the German giant Bosch with its solution (Figure 6), which includes an electric motor, gearbox and power electronics. The Bosch e-axle is highly variable and the customer can choose from various powerful motors from 50 kW for small cars or hybrids up to 300 kW for pure electric cars. The torque is in the range of 1,000 to 6,000 Nm.

Figure 6. E-axle from Bosch

It is definitely worth mentioning Schaeffler's E-axle and the use of a planetary differential, which replaces the traditional conical differential. This solution is very compact and its small dimensions in the radial direction leave more space for the engine itself. The gearbox is planetary and its gear ratio is 15. The electric motor is synchronous with permanent magnets with having power 150 kW, a maximum torque of 3,750 Nm and a maximum speed of up to 18,200 rpm. The weight of the whole system in the mentioned configuration is 75 kg.

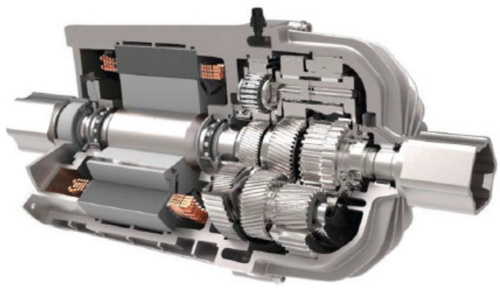


Figure 7. E-axle from Schaeffler

Conclusion

Electric motors are an irreplaceable part of an EV, on the other hand, their simple construction will probably not see any major breakthrough. Electric vehicles most often use synchronous motors with permanent magnets, which offer an ideal ratio between the supplied torque and efficiency. The main problem with these motors and the reason for looking for other solutions is the need to use expensive permanent magnets. Currently, the only possible alternative is the induction motors. DC motors have been popular, but they are no longer often used in electric vehicles today. An interesting possibility may be the use of reluctance motors, which, due to their properties, have a great potential to assert themselves and replace the currently used electric motors.

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