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Lozica Ivanović<sup>1</sup>,  
Slavica Miladinović<sup>2</sup>,  
Blaža Stojanović<sup>3</sup>,  
Miloš Matejić<sup>4</sup>

## APPLICATION OF MAGNETIC TRANSMISSION IN AUTOMOTIVE INDUSTRY

**ABSTRACT:** Transmissions in which the transmission of power and torque performed with the aid of non-contact magnetic force called magnetic transmissions. This magnetic transmissions, as opposed to mechanical gear transmissions, no noise, vibration and friction, and therefore does not need lubrication and maintenance costs are significantly lower. There are two basic types of magnetic transmissions: converted and magnetic transmissions with a variable magnetic field. Magnetic transmissions are made of an alloy of iron, boron and neodymium, which enables to obtain a permanent magnet for maximum utilization of power transmissions. This paper presents a brief overview of the development of magnetic transmissions, their classification and characteristics, of which the most important gear ratio and density of torque. Also, they are given examples of the application of magnetic transmissions in the automotive industry.

**KEYWORDS:** magnetic transmissions, transmission ratio, the density of torque, the vehicles, the automotive industry

### INTRODUCTION

In most cases, today, for the transfer of power in machines are used mechanical gear transmissions. Mechanical gear transmissions have a high density of torque, but for them there is friction which causes cancellation of gears, also the noise, heat and vibration are present, so the reliability of this transmissions is in question.

Increasingly, in designing of new products takes into account the conservation of energy and therefore the environment. The objective is the reduction of noise, vibration, making less maintenance, reduce heat, and a reduction in size.

The first magnetic transmissions proposed by Armstrong in his patent [2] from 1901. This magnetic transmissions was similar mechanical gear transmissions, the difference was that the magnetic gear has a winding coils on tooth through which passes the current, creating a magnetic field. Besides the magnetic transmissions whose transmissions rather resemble to conventional cylindrical gears transmissions, we also have magnetic transmissions resembling a mechanical planetary gear transmissions. These magnetic planetary transmissions are

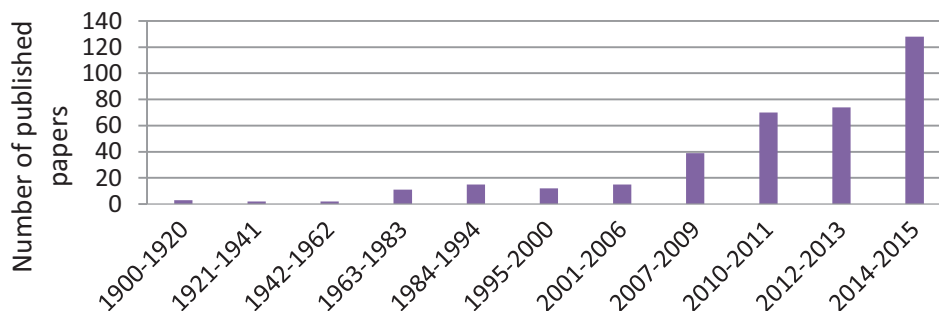
<sup>1</sup> Lozica Ivanović, Ph. D., assoc. prof., University of Kragujevac, Faculty of Engineering, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, [lozica@kg.ac.rs](mailto:lozica@kg.ac.rs)

<sup>2</sup> Slavica Miladinović, Research assoc., University of Kragujevac, Faculty of Engineering, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, [slavicam@kg.ac.rs](mailto:slavicam@kg.ac.rs)

<sup>3</sup> Blaža Stojanović, Ph. D., assist. prof., University of Kragujevac, Faculty of Engineering, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, [blaza@kg.ac.rs](mailto:blaza@kg.ac.rs)

<sup>4</sup> Miloš Matejić, teaching assistant, University of Kragujevac, Faculty of Engineering, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, [mmatejic@kg.ac.rs](mailto:mmatejic@kg.ac.rs)

first introduced in the patent in 1916 [26], then the Riz 1963 patented yet another planetary magnetic transmissions [28]. At the end of the 20th century Akerman has patented his magnetic planetary gear solution given in [1]. In a scientific paper [30] provides a historical overview of magnetic transmissions, as well as achievements accomplished in this area. There are many scientific papers and patents on the topic of magnetic transmissions, in Figure 1 is shown statistics of scientific papers published from 1900 to 2015 obtained from the literature [30,25], and the available data on issued work.



**Figure 1** Statistics of published works

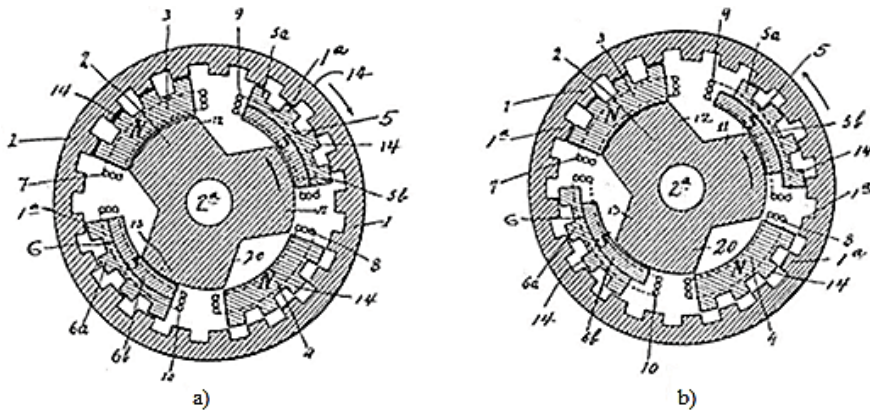
Some hybrid vehicles in themselves have magnetic transmissions, in [10,20,27] provides an example of using this transmissions. The company Magnomatics has developed a combination of engine and transmission, which is named Pseudo Direct Drive as well as MAGSPLIT who found application of hybrid vehicles, more of these transmitters is given in [35]. Mu Chen's paper [5] compared the performance of non-rare-earth and rare-earth permanent magnets, which can be used in transmissions hybrid cars. New electrically controlled magnetic variable-speed gearing (EC-MVSG) machine, which allows you to control the transmission ratios for use in hybrid vehicles proposed Liu Chunhua in their work [21]. The proposed machine can not only offer a gear-shifting mechanism for torque and speed transmission, but also provide variable gear ratios for torque and speed variation. Also, L. Jian in [11] proposed a transmissions for hybrid cars.

Further work will be given to the division of magnetic transmissions, their transmission ratios, torque density as well as their application in vehicles.

## HISTORY OF MAGNETIC TRANSMISSIONS

In the industry for transmission of power and torque from one shaft to another commonly used gear transmissions. Transmissions in which the transfer of power performed the by coupling a gear teeth are called mechanical gear transmissions. The first such transmissions have occurred even before the new era. Today, mechanical gear units have a very broad application. The disadvantage of this transmissions is a great noise, friction, maintenance costs, vibration and heat. With the development of technology tends to develop other ways to transfer power and torque, whereby the noise, vibration, maintenance costs, etc. were lower. One of those ways is the use of magnets in the transfer of power.

The first time magnet was mentioned as a transmission of power is by Armstrong (C. G. Armstrong) and that in its patent number 687292 [2] in 1901. The principle of the transfer of power with the magnetic transmissions is similar to the mechanical except that the transfer performed contactless, by magnetic force. Magnetic forces were obtained by passing a current through the coils, which are located on the drive gear teeth. As initiator of the idea of magnetic transmitters is considered a patent in 1916 [26]. In Figure 2 a) shows the cross-section of a magnetic concept transmissions which parts of the schedule such that the challenges of rotation of the drive gears and driven in opposite directions at different speeds. Figure 2 b) shows the same concept of magnetic transmissions in which the arrangement is such that it causes the rotation of the drive gear and driven in the same direction at different speeds.



**Figure 2** Patent from 1916. [26]

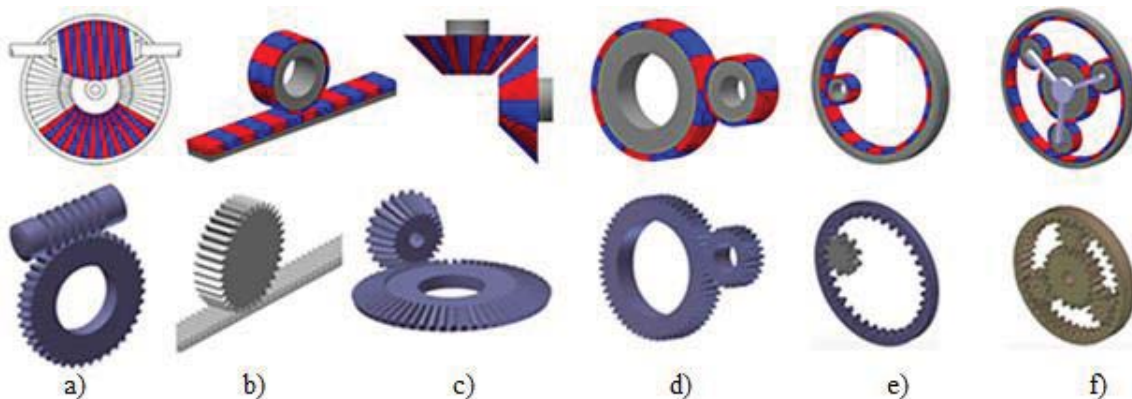
There are many patents on the topic of magnetic gears. There are also patent cylindrical magnetic gear which published Hazel (Hetzl) 1974. [7]. Planetary gear patented Mab (Mabe) 1991 [22]. Kikuchi and Tsurumoto in 1993 experimented with magnetic worm gears [14], and Jao et al peak magnetic gears in 1996 [33]. Akerman in 1999 issued a patent for planetary magnetic gear [1].

As a material for permanent magnets is first used ferrite who had bad qualities. 1980s with the advent of new material neodymium-iron-boron (NdFeB), which had better features, magnetic gears again come into the limelight.

Concentric magnetic transmissions have higher torque density than conventional magnetic transmissions.

## KINDS OF MAGNETIC TRANSMISSION

Magnetic transmissions are divided into two types, namely to converted magnetic transmission and magnetic transmission with variable magnetic field. Converted magnetic transmissions, which is also known as magnetic transmissions with direct effect, its shape reminiscent of a mechanical only instead of teeth have magnets. In this group can be classified many magnetic transmissions, some of them are: worm gear magnetic, magnetic rack and pinion, bevel magnetic gear, cylindrical gear (external and internal). Figure 3 shows a comparative view of magnetic and mechanical gear transmissions.



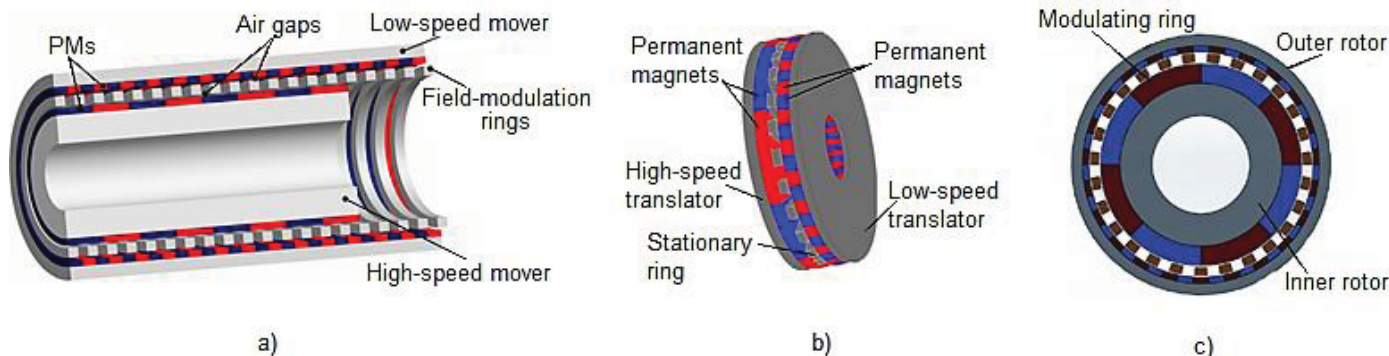
**Figure 3** Comparative view of magnetic and mechanical gear transmissions [30]

In addition to these transmissions, there are also gearing complex shape, such as a magnetic gear with helical teeth, worm gear and magnetic gear with a bypass shaft axis. These transmissions have suggested Tsurumoto and Kikuchi, they are described in more detail [13,14,32]. In [15], also described hyperboloid gear with radial magnetization and hyperboloid north and south pole. In the converted magnetic transmissions include even magnetic planetary gears and variators. Torque to be transmitted by means of the planetary gear depends on the number of satellites, respectively, can be increased with increasing number of satellites but also increases the moment of inertia. The good side of this transmissions is that they have a large transmission ratio, high torque density and three modes. The downside of this transmissions is that with the increasing number of satellites increases the complexity of the transmissions. At [16,9] is described the development of magnetic planetary gear and an analysis of the transmissions, and the [17] described their use in devices with variable inertia.

Field-modulated magnetic gears, also called the magnetic flux guided transmissions. Unlike the previous type of transmissions in which the gears are a very short distance, so that magnetic flux travels from one gear to another

through the air gear, with the transmissions with a variable magnetic field, there is a piece of iron that leads flux from one to another gear. There are plenty of patents transmissions with a variable magnetic field. In these transmissions include [30]: Linear concentric magnetic gear, axial magnetic gear and coaxial magnetic gear.

Linear magnetic gear is described in [3,29], a tubular form and his work is based on the change of the magnetic fields produced by two motors with permanent magnets between which there are ferromagnetic parts which are used for the modulation of the magnetic field. In Figure 4 a) shows a magnetic one such gear with labeled parts. Axial magnetic gear proposed in [24], one such gear is shown in Figure 4 b). Coaxial magnet gear (CMG) is shown in Figure 4 c), consisting of the outer and inner rotor, and a modulator which is situated between them. The modulator consists of a cage that includes the parts of a ferromagnetic material, the ferromagnetic material provides modulation (changing) magnetic field. This notebook was first mentioned Martin in his patent [23], but on its large magnetic density are discussed in [19,31]. The inner rotor is usually higher speed rotor rotation, and external rotation of the lower speed range.



**Figure 4** Field-modulated magnetic gears a) linear magnetic gear [18] b) axial magnetic gear [24], c) coaxial magnetic gear (CMG) [19]

### Advantages of magnetic transmissions

Comparative characteristics of mechanical and magnetic transmissions are given in Table 1. Some of the advantages of magnetic transmissions is no noise or vibration, no contact and therefore no need to use a lubricant, a magneto gears can transmit higher torques than the mechanical gear transmissions. Some magnetic transmissions can be physically separated, however, for example. can be used in the food and chemical industries. In this transmissions overload will not damage the transmissions, but will happen slip gears.

**Table 1** Ratios and density of torque for mechanical and magnetic transmissions [19]

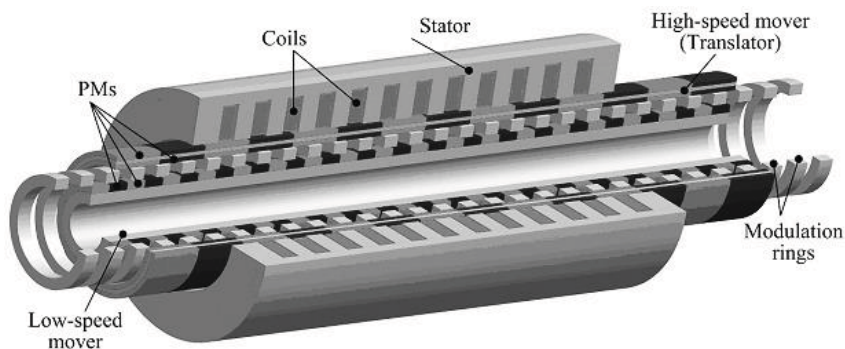
Gear type	Transmission rate	Torque density [kNm/m <sup>3</sup> ]
Mechanical spur gear	1.4–28000	100–200
Multielement MG [1]	24 : 1	3.96
Involute MG [2]	3 : 1	1.7
Magnetic worm gear [13]	33 : 1	0.74
Magnetic skew gear [14]	1.7 : 1	0.15
Parallel-axis MG [19]	4 : 1	11.6
Perpendicular-axis MG [20]	1 : 1	3
Magnetic torque coupler [26]	1 : 1	51.9
MPG [28]	3 : 1	97.3

### APPLICATION OF MAGNETIC TRANSMISSION

As the present time it weighs less environmental pollution, and renewable energy sources, increased interest in magnetic transmission. As already stated, these gear lubrication is not necessary and there is no danger of a lubricant poured into eg. water. Also silent were the very good side of the transmissions.

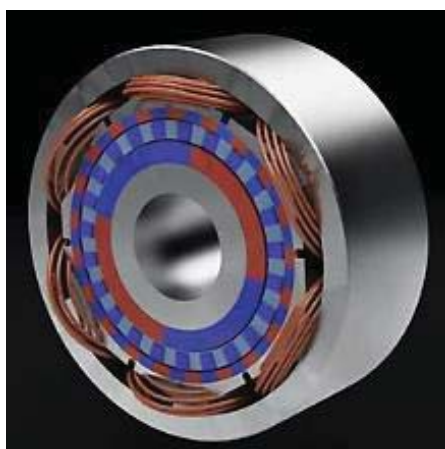


In hybrid vehicles can be used linear, planetary, and even coaxial magnetic transmissions [10,20,27]. Figure 5 shows picture of a linear transmissions used in vehicles [19].



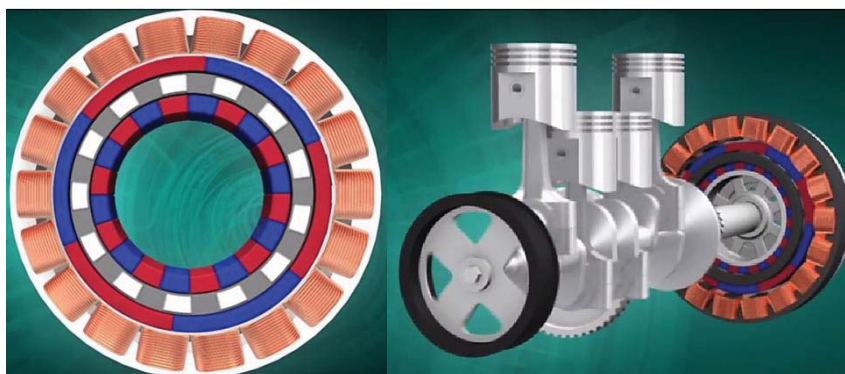
**Figure 5** Linear magnetic transmissions in vehicles [20]

The company Magnomatics succeeded to combine the magnetic gears with stator with windings, thus getting Pseudo Direct Drive (PDD). PDD is a replacement engine and gearbox and can be used wherever used conventional motor and gearbox. A PTD is shown in Figure 6 [35].



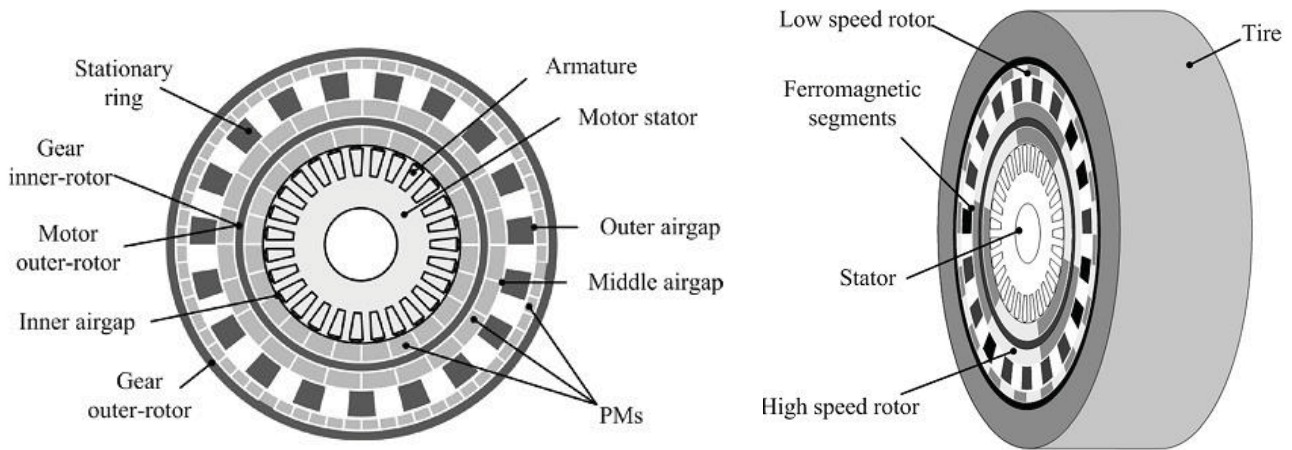
**Figure 6** Pseudo Direct Drive (PDD) [35]

For hybrid vehicles the company Magnomatics has developed MAGSPLIT (Figure 7) used for rate variation, which is a substitute for conventional eCVT systems in these vehicles [35].



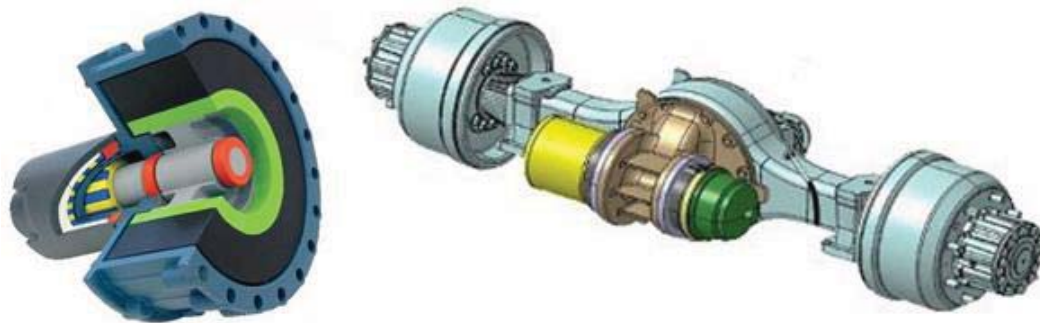
**Figure 7** MAGSPLIT [35]

Linni Jian in [12] gave the design and analysis of magnetic motor for electric vehicles, with the magnetic gear transmissions of this engine was used Halbach's the schedule of permanent magnets. Figure 8 shows a motor built in the wheel of the vehicle.



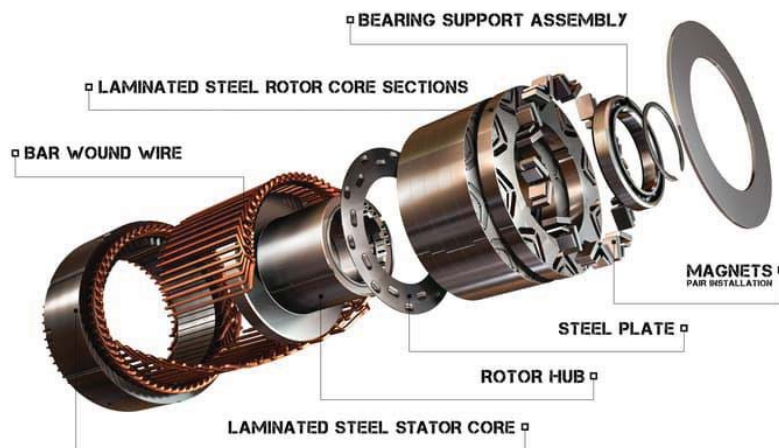
**Figure 8** Halbach magnetic geared permanent magnet Motor [12]

The company Ricardo has patented mechanism with a magnetic gears and magnetic couplings, as shown in Figure 9 left. This company has developed and Kinergy flywheel system which is very compact and is shown in Figure 9 right. Flywheels are particularly good for vehicles that often perform the function of braking, thus, cars, trucks, trains, trams, buses, machines, material handling, such as cranes and elevators, and even vehicles for delivery [6].



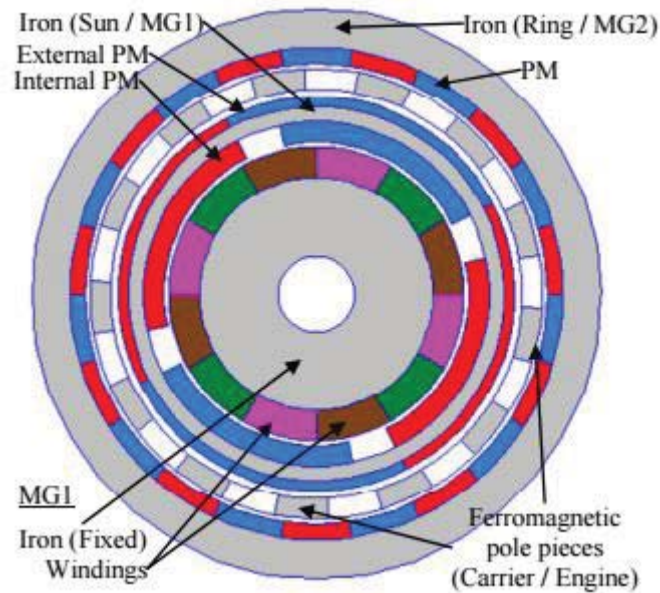
**Figure 9** Left Ricardo's flywheel, right Kinergy flywheel system integrated into a rear axle assembly [6]

General Motors in its model Chevrolet Spark EV is changed motor with permanent magnets is shown in Figure 10.



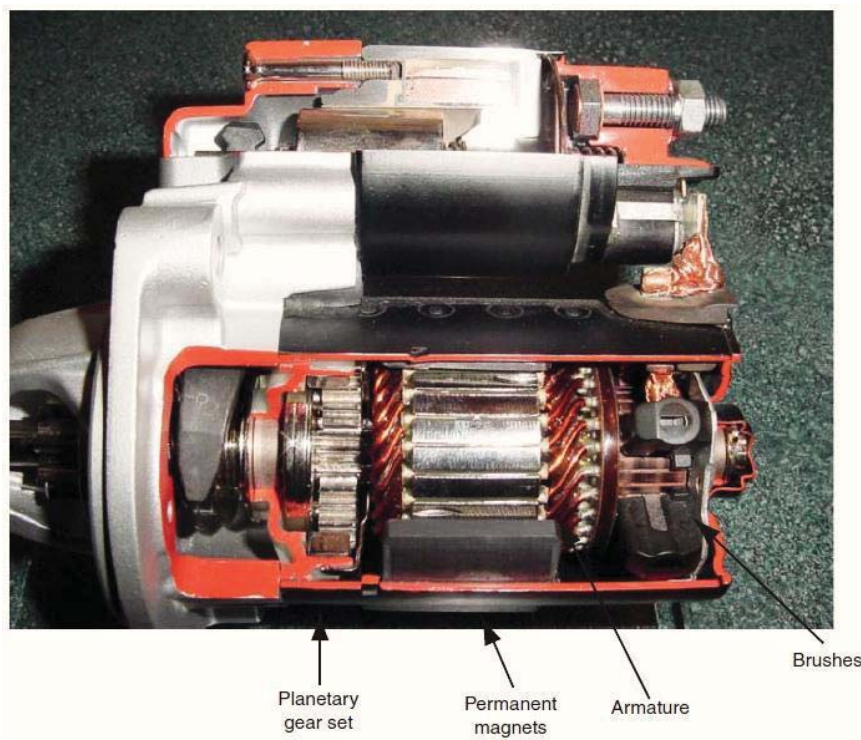
**Figure 10** GM's permanent magnet EV motor [34]

In [4] a mechanical planetary gear hybrid vehicles replaced with magnetic planetary gear. In Figure 11, there is provided a solution of such a magnetic planetary gear where the MG1 and MG2 marked generator that is a permanent magnet synchronous machine.



**Figure 11** Magnetic planetary gear in hybrid vehicles [4]

The use of magnets for motors is given in [8]. Starter permanent magnet (PMGR- permanent magnet gear reduction starter) is a smaller size, simpler construction and less heat compared to conventional starters. One such starter shown in Figure 12, magnetic starter uses a 4 or 6 pairs of magnets instead of coils.



**Figure 12** PMGR starter [8]

These are just some examples of the application of magnetic transmissions vehicles. In the future, this application will be even greater, both in vehicles and in the industry.

## CONCLUSIONS

Today when environmental pollution is a global problem, the aim is to find technologies whose use would reduce environmental pollution, so the importance of receiving magnetic transmissions. The most importance is given to the use of magnetic transmission in wind turbines and hybrid vehicles. Combining magnetic gear with stator coil company Magnomatics has thereby Pseudo Direct Drive (PDD), which is the replacement of the engine and gearbox and can be used wherever used conventional motor and gearbox. Flywheels in combination with magnetic transmitters are a new way to reduce fuel consumption in vehicles. In magnetic transmission there is no damage, no noise, and the fact that it is not necessary lubricant in favor to increasing deployment of these transmitters.



Considering that this is a new kind of transmitters, it can be assumed that these advantages in the future affect the increasing application of magnetic transmission. Most, if not all of the kitchen appliances will have these transmitters, each hot drink in a cafe or food stored at home will be captured with the help of magnetic transmission. Buses, trains, light and heavy trucks, taxis and private cars will move with the help of magnetic transmission. All this will help to preserve the environment and improving the quality of life.

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