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A look into electric/hybrid cars from an ecological perspective

Andrea Aurora Racz[a], Ionuţ Muntean[b]*, Sergiu-Dan Stan[a]

[a]Faculty of Mechanical Engineering, Technical University of Cluj.Napoca, 103-105 Muncii Blvd, Cluj-Napoca,400641, Romania
[b]Department of Automation, Technical University of Cluj.Napoca, 26-28 Gh. Baritiu Str., Cluj-Napoca, 400027, Romania

Abstract

A worldwide problem today is environmental pollution, resulting in the greenhouse effect, therefore the appearance of eco-friendly cars is a great benefit to the environment. Technology has needed to evolve greatly to be able to power these automobiles over long distances and the process has not ended yet. In this run for evolution and efficiency, there are a lot of questions that still remain open and one of them is what happens at the end of the lifecycle of a battery and an electric motor. As the number of sold electric cars will increase, the amount of electric motors and battery waste will increase too thus leading to a greater impact on the environment. For this reason, in this paper, we present also the negative impact that the mentioned waste will have on the environment to act as a motivation for more research in this field.

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1. Introduction

Hybrid electric vehicles (HEV), initially sold only introduced in North American, European and Japanese markets in the second half of the 90's, are now starting to gain markets in developing and traditional countries, including China and Brazil [1]. At this moment, the technology that is implemented in hybrid electric vehicle manufacturing is sufficiently developed for a worldwide expansion.

* Corresponding author. Tel.: +40-264-202-437
*E-mail address:*ionut.muntean@aut.utcluj.ro

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A hybrid electric vehicle can be also named eco-friendly car [1]. Eco-friendly concept cars run on electricity or on a combination of electricity and hydrogen fuel. Both types lead to a reduction in transportation costs while at the same time reducing the CO_2 emissions. While reducing the amount of fuel consumption deals directly with the vehicle's efficiency, there are other components that may cause deleterious effects in the long-term. The battery component in the top hybrid vehicles are typically covered by an eight year warranty and consumer will have to deal with the replacement and disposal. Because it is a young industry, this subject has not come up as an issue, but as hybrids pervade the vehicular industry further and age, these issues will begin to emerge at the forefront [2].

Our paper will focus on electric/hybrid cars from an ecological perspective where not only the positives will be presented, but also the problems that appear at the end of the life of batteries and electric motors and the existent solutions available.

The paper presents in Section 2 a detailed description of electric and hybrid automobiles. In Section 3 the electric motors together with the main battery types used today in industry are presented. Section 4 presents the ecological perspective on electric/hybrid cars and in Section 5 the conclusions are drawn.

2. Electric/Hybrid automobiles

2.1. Electric automobiles

Currently, electric automobiles are created by using the same chassis as gasoline cars, so from the outside it is very difficult to distinguish an electric car from a gasoline car. The only thing that could indicate that the vehicle is an electric car is the low noise level that it produces. A simple definition of an electric car would be: an automobile whose gasoline engine was replaced by an electric motor [2].

The power transmitted to the motor comes from an array of rechargeable batteries and is regulated by a controller. The operating principle of an electric car is based on DC controllers that take power from the battery and modulate it in such a manner that the motor receives only the amount of power that it requires. The throttle signal is supplied to the DC controller to indicate the power level to be sent to the motor.

Electric vehicles (EVs) are one of the most promising ways to increase energy efficiency and to reduce greenhouse gases and in 2012, from data bases collected worldwide, the percentage of electric cars per country, out of the total number of automobiles, is the following:

- France – 11%
- China - 6,2%
- UK – 4,4%
- Denmark – 3,6%
- Germany – 3%
- Japan -2,4%
- Portugal – 1%
- Italy -0,9%
- India – 0,8%
- Netherlands -0,7%
- Sweden -0,7%
- Spain -0,4%
- Finland -0,1% [3].

2.2. Hybrid automobiles

Any vehicle with two sources of power can be called a hybrid vehicle [4].

Hybrid cars get their power from two sources, a gasoline engine and an electric motor. Hybrid cars are designed that in some cases both power sources are used simultaneously and in others the sources are used alternatively. For example, when a hybrid car runs at speeds below 5-10 km/h, e.g. when approaching or leaving a traffic junction, it runs only on the electric motor, which reduces the fuel consumption.

In hybrid cars, the electric motor gets its power either from batteries, batteries than can be recharged while the car is braking (regenerative braking), or when idling, from an external power source. Another recharging technique is when the internal combustion engine is connected to a generator that directly recharges the batteries.

For hybrid cars there exist two different design schemes on how the internal combustion engine and the electric motor are connected [5]. The first scheme is the series connection where the combustion engine is used to recharge the batteries, the electric motor being in charge of the traction. Another connection scheme is the parallel connection where both engines are used to power the car, the torque of the two engines being regulated by a controller.

Hybrid cars can be called mild or full hybrid, the difference between the two consists in how the electric motor drives the car. If the motor can drive the car without the gasoline engine, then the automobile is called full hybrid, and if not then the automobile is called mild hybrid [6].

2.3. Comparison between electric and hybrid cars

Both electric and hybrid cars are considered to be eco-friendly, but at the same time the following differences exist:

In hybrid cars, the carbon dioxide and other harmful emissions are reduced, reaching zero in electric cars [7].

The hybrid car is quieter than one with an internal combustion engine, electric cars being even quieter [8].

The battery that powers the electric motor from electric cars need to be recharged. The battery from hybrid cars does not need to be recharged because, in most cases, it recharges automatically when the car is in use [9].

3. Electric motors and batteries used in electric and hybrid cars

The main components in electric and hybrid cars that have been modified in comparison to an internal combustion engine are the motor and the batteries. Next, we will focus next on these two elements and on their characteristics.

3.1. Electric motors

The electric motors are devices that convert electrical energy into mechanical energy and are part of the electrical system of a car, two types being currently implemented in automobiles: direct current (DC) motors or alternating current (AC) motors [10].

The electric motor in comparison with internal combustion engines has more advantages:

- Low initial cost –the initial cost of an electric motor is considerably lower than a fossil-fuel engine;
- Long life and little maintenance required –electric motors offer over 30.000 hours of operating time without requiring major repairs;
- High efficiency –electric motors are highly efficient, with a rating ranging from 50% to 95% (depending on the size of the motor and the operating conditions);
- Environmental safety –electric motors emit little to no noise, reduce the emissions of carbon dioxide and other harmful gases thus, during their lifetime, having very little negative effect on the environment;
- Labour cost savings –electric motors are smaller and easier to control, the maintenance being done quicker and easier resulting in lower costs [2].

Electric motors have though one major disadvantage: demand charges – using high-horsepower motors in application can results in a high cost per hour of operation [2].

Currently, researchers are developing solutions for recycling electric motors, and they are focusing on permanent magnets, which contain many rare earth elements such as Nd, Dy, Tb and Pr. Building a compact and lightweight electric motor requires approximately 30% of the range of rare metals. In the coming years, the production of electric and hybrid cars will increase, requiring the development, for this type of motors with permanent magnets, of new technologies in order to reduce the use of raw rare earths metals.

The electric motors, for electric and hybrid vehicles, does not necessarily contain rare earth metals, several types of electric motors built without permanents magnets being in use. This types of electric motors without magnets are cheaper, and are generally AC motors, for example the Tesla Roadster is equipped with an electric motor without rare earth metals [11].

Alternatives, proposed by researchers from the field of electric motors recycling, include the removal of magnets from scrap motors, repair and subsequent reuse of the electric motor or its components [14].

For the moment, when an electric motors reaches the end of its life cycle, after dismantling and analyzing, one can say if the electric motor can be repaired, start a new life cycle, or recycled by components.

3.2. Batteries

The battery is a device for storing chemical energy and converting it into electricity. All battery technologies have two fundamental characteristics that affect battery, design, production, cost of operating, performance and durability:

- Power density –the amount of energy over the period of time in which the energy can be delivered and
- Energy density –the amount of energy stored in the battery [15].

Between these two features, there is usually a compromise to be made, some batteries having higher power density and a lower energy density and vice versa.

Ever since the appearance of the electric and hybird vehicles researches have been made on how to improve the recharge cycles, durability of the batteries etc. For example, the durability is one of the most important characteristics and it's represented by the life cycle of a battery. The life cycle of a battery is given by the number of charging– discharging cycles. Another factor that affects the durability of the battery is the temperature, low or high temperatures affecting strongly the life of a battery.

Another drawback for batteries is the necessary time to recharge, currently existing three common recharging methods:

- Conductive charging – the charging process is simple, the electric vehicle needs to be plugged into a standard 13A socket with a dedicated circuit and protective device. It is easy and convenient, but it takes a long time, ranging from 8 to 10 hours for a complete charge;
- Inductive charging – a charging process without the need of a cable connection. The energy from the charger and is transmitted to the vehicle through a magnetic field using high AC current. The process is complex and expensive because of the reuired equipment;
- Battery swapping – another charging process that doesn't require cable connection. Here, the discharged batteries are replaced with fully charged ones, however the user does not own the batteries, but pays a rental fee [16].
- Regarding the battery types, the most common ones are:
- Lead-acid batteries;
- Nickel metal hybrid batteries (NiMH);
- Lithium-ion batteries (Li-ion).

The first rechargeable batteries were lead-acid ones and were invented in 1859 in France. The lead acid batteries are a mature industrial product, which are produced in large volumes.

A common lead acid battery is a mono-block construction with six cells, each cell containing 19 electrodes that deliver a nominal voltage of 12 volts. The cell capacity is 75 A and each 12 volt battery module has a nominal energy of 900 Wh [17].

Dr.Vasant Kumar from the University of Cambridge has developed a new process to recycle lead-acid batteries. The method comprises of dissolving, in a leaching-precipitation process, the lead-bearing active components of battery paste in an aqueous solution of carboxylic acid and precipitating a lead bearing organic precursor. The lead organic precursor is converted by combustion-calcination to lead monoxide containing an amount of metallic lead as desired for direct battery paste preparation. The organics embodied in the precursor serve as fuel by combustion to aid calcination. Any residual lead sulphate that escapes fixing in the solution during leaching is also used, as it can be recovered in the calcined lead product in the form of binder for the preparation of the precursor for making new lead acid batteries [18].

A typical Nickel-Metal battery has a 90 to 100 Ah cell capacity with a prismatic cell configuration.The average lifetime varies from 2 up to 5–7 years. About 65% of the used batteries are not disposed of but kept by the user (so-called hoarding) [19]. This is a direct consequence of the fact that users do not regard used batteries as disposable.

Because the NiMH batteries are a relatively new product, recycling technologies are still under development. The most common proposal is made for the pyrometallurgical recycling of NiMH, much research having focused on the hydrometallurgical treatment [19]. The hydrometallurgical processes are though difficult to put into practice due to their high complexity.

Unfortunately, none of the proposed recycling processes are used at an industrial scale, the most common technology to recycle NiMH batteries is to use them as a cheap source in stainless steel production [19].

Most car manufacturers are still using nickel metal hydride (NiMH) batteries, but because the lithium-ion batteries offer a better performance, smaller weight and higher cell potential, the nickel metal hybrid batteries are expected, in the near future, to be replaced with the lithium-ion batteries [20].

The lithium-ion batteries were first developed in the United States and Europe, however Japanese companies were the first to commercialise the batteries in the early 1990s. Manufacturing moved then to China and Korea in the early 2000s and at the end of the first decade of this century south-east Asia was dominating the manufacturing of lithium-ion batteries, with 98% of the global production. Today, the United States are investing in creating local production sites for lithium-ion batteries, while Asian companies strive to capture the market for electric vehicles [21].

The recycling process in the lithium-ion batteries consist in a mechanical processing where the batteries are crushed in a CO_2 environment, so the volatile organic electrolyte evaporates and is collected as non-usable condensate. A subsequent material separation is done with the different material fractions being sold as feedstock for other processes.

Originally, the hydrometallurgical Toxco (recycling method) process was developed for the safe recycling of used lithium-ion primary batteries. Today's facility processes used lithium-ion secondary batteries as well.

If necessary, the batteries are treated by Toxco's (recycling method) patented cryogenic process, i.e. they are cooled to about −200 °C. Lithium, although normally explosively reactive at room temperature, behaves almost inert at very low temperatures. The batteries are then safely shredded and the materials separated. The lithium components are separated and converted to lithium carbonate for resale. If the batteries contain cobalt, then this component is also recovered for production of $LiCoO_2$ as new battery electrode material [22].

4. Ecological perspective

The biggest change that has been brought by these eco-friendly cars was the noise reduction and a lessening of the air pollution by reducing the carbon dioxide and other harmful emissions [23]. The new concept of eco-friendly car is a good start for a healthier environment, but at the same time more attention needs to be paid to the recycling process because the benefits of electrical batteries are always mentioned, however the negative effect of the recycling process is often skipped.

From many studies, it results that until 2020, in US alone, around 6 million electric vehicles could be sold, the number raising to 11 million worldwide [24]. If the numbers of electric vehicles will follow the estimated figures, then a well-defined end of life strategy for the electric engine and batteries removed from electric vehicles is required. Only afterwards can the auto industry be called an environmental friendly industry [24].

The first step in developing well-defined end of life strategies for batteries is the necessity to know their composition in order to choose the correct recycling process. By recycling them, 30 % of the energy can be recovered. A generalized recycling process for batteries uses water and energy to separate the wastes from viable substances.

After the recycling of 1 kg electric battery, the substances that are released in solids, water and air are approaching:

- 0,24 kg slag and 30 g toxics to solid;
- < 0,1 kg Sb, Hg, Ni, Pb, Cd to water;
- < 5 g Pb, Cd, Cu, Zu, As, Ni to air [25].

The recycling process is thus harmful especially for the people who are working in the recycling process laboratory because, for example, mercury can be absorbed through the skin other harmful toxins can be inhaled or ingested.

One can say that the recycling process can be a dangerous process for humans and the environment if the correct strategies are not properly applied [26].

5. Conclusions

Concerns about the environment and rising costs of fossil fuels are driving automakers to design and build cleaner, more energy efficient vehicles, represented especially by hybrid and electric vehicles. This reduces the CO_2 emissions and other harmful emissions thus having a lower impact on the environment.

The main drawback is the energy source: the batteries. Rare earth elements are available in limited quantities and expensive, therefore researchers are developing solutions for extracting as much as possible from discarded batteries. Unfortunately, none of the proposed solutions is used at an extensive level. Based on their potential, though, the time until they reach industry scale is not far away.

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