Looking Back to Electric Cars

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***Abstract* — Very early experimental electric cars appeared just after electromagnetism was discovered, in 1820. During the nineteenth century they underwent improvements, staying in advance of internal combustion engines. A breakthrough came with the inventions of the rechargeable battery and of powerful and efficient electric motors, around 1870. Electrics peaked around the turn of the century, when they hold 38% of the automobile market in the US, compared with 40% of steam and 22% internal combustion. Their decline started in the second decade of the twentieth century when the internal combustion engine had a major boost, thanks to important advancements in the infrastructure, product and production technologies.**

***Index Terms* — Electric, car, automobile, DC motor, rechargeable battery.**

I. Introduction

One of the major symbols of modern civilization is the automobile that over a century has allowed an unprecedented personal mobility. As a confirmation of its position in our culture, today's cars are not just tools that help us in our daily transfers, but also status symbols of social success, with luxury models made by brands such as Rolls-Royce and Mercedes-Benz and of technological perfection, with racing vehicles developed by manufacturers such as McLaren and Ferrari. The latter's headquarters are about 180 km from the venue of this conference, a distance that road vehicles derived from its competition models could cover in less than half an hour. Car technology is closely related to its conventional motor, the internal combustion engine (ICE), especially in the Otto and Diesel designs, to the extent that automobile and ICE in our imagination are fused into a unique concept.

However in recent years increasing attention to environmental pollution and concern about the depletion of oil reserves worldwide have raised attention to electric and hybrid cars, which are seen as viable alternatives to gasoline-powered vehicles. Many countries are funding important research programs aimed at developing and perfecting the technology of electric cars, including advanced high-efficiency motors, high-energy-density long-lasting batteries, of both the rechargeable cell and fuel-cell types, and innovative power management and control systems with regenerative breaking. When we consider electric cars in this framework, they appear to our eyes as advanced technologies in comparison with conventional ICEs. Nevertheless more that a century ago electric cars, in advance on gasoline, were already running.

II. Automobiles before electricity

If we look back to our far history, we can realize that man has always been fascinated by speed and our first attempts to move faster than a galloping horse date way back in the past, long before motors were built. Wind was the first energy source other than muscles to be exploited for motion. In fact, presumably around the beginning of the third millennium B.C. ancient Egyptians harnessed it with sails to thrust their papyrus-made keel-less ships upstream the river Nile. First wind-propelled sailing chariots, capable of high speeds over land, were reported in China in the VI century AD. In Europe a similar vehicle was made only one millennium later by the Flemish mathematician and polymath Simon Stevin (1548/49-1620). It was used for amusing prince Maurice of Nassau with racing along the sandy Dutch beaches between Scheveningen and Petten and was reported to run faster than horses.

Before Stevin other European technicians had conceived more complex self-propelled cars. A very early design was envisaged by Italian engineer Guido da Vigevano (~1280-~1349). In 1331 he sketched in his *Texaurus regis Francie* a windmill-powered battle car for king Philip VI of France who was planning a crusade that was actually never done (Fig. 1). As far as we know this was the first idea in Europe for a vehicle not reliant on muscle power.

Around 1478 also Leonardo da Vinci (1452–1519) designed a self-moving car, i.e. an automobile, for stage uses (Fig. 1). Comprehensive studies of his drawings in the *Codex Atlanticus* have recognize that this car was powered by large coiled springs located in cylindrical drum-like casings. Spring drive had just appeared in Europe, with early use in much smaller devices such as portable clocks around 1440. Leonardo's automobile was the very first stored-energy internally propelled vehicle. It is believed that Leonardo actually built and used it, but it was too ahead of its time and, as often in such cases, had no developments.

The thought of powering a car with steam was conceived before Thomas Newcomen and James Watt had built their steam engines. The first idea of this kind was a toy car designed by the Flemish Jesuit missionary Ferdinand Verbiest (1623-1688) while staying in China around 1672, who resorted to the steam-turbine proposed by Italian engineer Giovanni Branca (1571-1640) in 1624 in his mechanical treatise *Le Machine: volume nuovo et di molto artificio*…

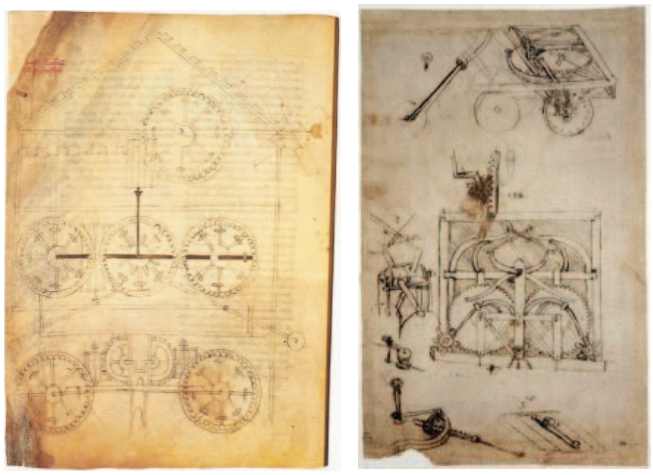

Figure 1. Drawing of Guido da Vigevano's of windmill-powered battle car, from *Texaurus regis Francie* (1331) and drawing of Leonardo da Vinci's spring-driven stage car, from *Codex Atlanticus* (around 1478).

As a matter of fact, as soon as technological progress provided motors capable of generating mechanical power, inventors began to devise the way to exploit them for powering vehicles. This was the case of Nicolas-Joseph Cugnot (1725–1804), the French army engineer officer who around 1770 first built a real car (a tricycle 7.25 m long travelling at 4km/h) propelled by a steam engine, that was intended for transporting cannons. Apart from exhibiting inadequate breaking system and stability problems, the car was prone to the low efficiency and the poor power-to-weight ratio of its steam engine, even when compared with the primitive standards of the day (Watt developed his "higher-efficient" condenser engine only in 1774). Better performance was obtained in 1784 by British Richard Trevithick (1771-1833) with his small "high-pressure" steam locomotive, that profited of recent progresses in steel and steam technologies.

In 1807, just after hydrogen productions had become viable, the French-Swiss inventor François Isaac de Rivaz (1752-1828) constructed the first successful albeit primitive ICE, fed with a mixture of hydrogen and oxygen, and the following year used it to power the forerunner of ICE automobiles. However it remained unique for decades, particularly after Carnot's thermodynamic theory of 1824 had highlighted the fundamental shortcoming of this kind of engine.

III. Emerging of electrodynamics

The experiment performed in 1820 by Danish physicist and chemist Hans Christian Ørsted (1777-1851) by observing the deflection of a compass needle in proximity to an electrical current not only marked the discovery of electromagnetism, i.e. the interaction of electric and magnetic fields, but also highlighted the possibility of obtaining mechanical actions much stronger than electrostatic ones by means of dynamic electricity [1]. In a similar way as had happened for elastic energy and pressure, early attempts at building electric-propelled cars appeared just a few short years after Ørsted's seminal achievement.

As early as 1822 English mathematician and physicist Peter Barlow (1776-1862) was able of producing the continuous rotation of a spiked disc by the interaction between a magnetic field and an electric current. However the Barlow's wheel, how it is known, was a crude set-up not suitable for developing useful mechanical actions.

Even earlier, stronger electrodynamic forces were obtained with the electromagnetic multiplier (the first coil), built in 1820 by German physicist Johann S. C. Schweigger (1779-1857). In 1825 English physicist and inventor William Sturgeon (1783-1850) was able to obtain even stronger mechanical actions by adding the electromagnetic multiplier with an iron core (the first electromagnet) that was capable of lifting a nine pounds weight (4 kg). In 1828 American scientist Joseph Henry (1797-1878) improved the device by insulating its coil with silk ribbon and tightly winding it around the core. By using such electromagnets he was later capable of lifting bodies as heavy as one ton. The way was paved for producing forces suitable for motion.

IV. Early electrical cars

In fact, early rudimentary electric motors were constructed and soon used to move cars. In 1827 Slovak-Hungarian priest Ányos Jedlik (1800-1895) built the first crude but viable electric motor, provided with stator, rotor and commutator, and the year after used it to power a tiny car (Fig. 2). A few years later, in 1835, professor Sibrandus Stratingh (1785-1841) of University of Groningen, the Netherlands, built a small scale electric car (Fig. 3) and a Robert Anderson of Scotland is reported to have made a crude electric carriage sometime between the years of 1832 and 1839.

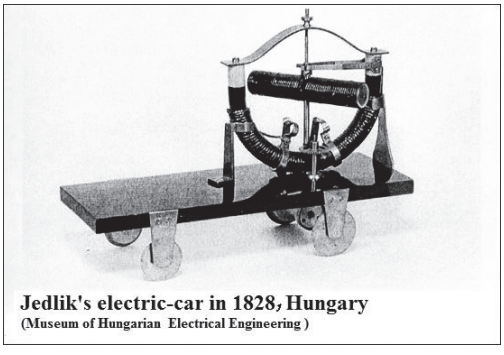

Figure 2. Jedelik's toy electric car, 1828 (courtesy of Museum of Hungarian Electrical Engineering.)

Around the same period, early experimental electrical cars were moving on rails, too. In 1835 American blacksmith and inventor Thomas Davenport (1802-1851) built a toy electric locomotive. It was powered by a primitive electric motor he

had constructed the year before, derived from Henry's electromagnets. Scottish entrepreneur and inventor Robert Davidson (1804-1894), following the fad for electricity of the day, started experimenting on electric motors in 1827 and created the first real size electric locomotive dubbed "Galvani" in 1842. It was tested on the Edinburgh-Glasgow line that same year, at a speed of 4 mph with no passengers nor goods on board. This four-wheeled vehicle was powered by disposable batteries, like all other electric vehicles of that time. The same solution was adopted by American electrical experimenter Charles Grafton Page (1812-1868), when in 1851 he made a locomotive powered by his reciprocating electrical engine. Conducting rails opened the possibility to place the batteries apart from the car: the use of rails as conductors was patented in 1840 in the UK and in 1847 in the United States.

Figure 3. Stratingh's small electric car, 1835 (courtesy of University of Groningen.)

A. Limitations of early electrics

All those first generation electrical carriages were unsuitable for practical exploitation. Their motors were based on the same basic scheme, consisting of combined electromagnets automatically operated in sequence by primitive commutators, resulting in poor efficiency and power. The only available generators were early electrochemical cells based on the depolarized type developed in 1829 by the French scientist Antoine-César Becquerel (1788-1878), the zinc-platinum cell made in 1830 by Welsh lawyer and chemist William R. Grove (1811-1896), and the improved double electrolyte depolarized cell introduce in 1836 by the English chemist and physicist John Daniell (1790-1845). A more viable model was proposed in 1841 by German chemist Robert W. E. Bunsen (1811-1899), who replaced the platinum electrode with a carbon one. Even so, those primary batteries had to be disposed of once exhausted, thus resulting expensive energy sources. It was calculated and demonstrated that the consumption of zinc in such batteries was forty times more expensive than burning coal in a steam locomotive (at that time steam railways were in full expansion).

Therefore those early electric cars could not achieve the success their inventors had hoped. Nonetheless they could run, and their development was ahead of ICE vehicles, which made a lonely and uncertain appearance in 1826 with the unfortunate car of American inventor Samuel Morey (1762-1843) and would take a substantial step forward only in 1863 with the motors developed by Belgian engineer Étienne Lenoir (1822-1900).

V. Advancements after Mid Nineteenth Century

Practical rechargeable batteries were lacking in the mid 19th century. In fact, they would be recharged with the only available generators of the time, namely primary cells, with a costly, inefficient and useless operation.

Viable dynamos appeared in the late 1860s, thanks to a series of developments that occurred in the two previous decades. Among the most outstanding we can cite; i) the battery-powered electromagnet excitation conceived by Danish engineer Sören Hjorth (1801-1870) in 1851 (patented in 1854), that allowed a higher excitation field; ii) the solid iron rotor introduced by prominent German entrepreneur and inventor Werner Siemens (1816-1892) in 1856, that further increases the excitation field; iii) the ring armature conceived by Italian scientist Antonio Pacinotti (1841-1912) in 1860 (published in 1963), that produced stronger and smoother currents with commutation exempt from dangerous sparks; iv) the self-excitation (produced by the dynamo itself, thus getting rid of the external power supply), introduced by Jedlik in 1861; v) the self-starting self-excited dynamo of Siemens appeared in 1867; vi) the dynamo built in France by Belgian electrician Zénobe Gramme (1826-1901) in 1869, where he merged all previous advancements, obtaining the first electromechanical generator capable of power as high as steam machines.

Those electromechanical generators, typically powered by steam engines, could produce for the first time virtually unlimited electric energy at costs much lower than primary electrochemical cells so that they paved the way for the spread of electricity in many different fields. When they became available, also the first practical rechargeable cell appeared, namely the lead-acid accumulator constructed in 1859 by French physicist Gaston Planté (1834-1889). The improved model developed in 1881 by French chemist Camille Alphonse Faure (1840-1898) achieved great success in the following decades.

DC electric motors were developed at around the same time as generators, still before the reversibility principle was annunciated by Siemens in 1867 and demonstrated by Pacinotti in 1869 and then by Gramme in 1873. Those advancements pushed DC motors towards maturity and together with rechargeable batteries they were ready to provide a major boost to electric vehicles [2]-[5].

VI. EARLY PRACTICAL ELECTRICS

A. *British electrics*

Electric advancements in Great Britain started in the 1870s, with Robert Davidson who in 1873, thirty-one years after his electric locomotive, built an electric car that is often referred to as the first working electric road vehicle. However it was still powered with disposable iron/zinc batteries, thus resulting burdened with excessive operational costs and unsuitable for industrial exploitation. In 1882 William E. Ayrton (1847-1908) and John Perry (1850–1920) built a light electric tricycle powered by a 0.5 HP motor fed by 10 Planté cells, hampered by the excessive weight of the batteries.

In 1884 Thomas Parker (1843-1915) built a more successful electric car, that was fed by the rechargeable batteries made by his company Elwell-Parker Ltd, which had been set up two years earlier (Fig. 4). Parker was a prominent British pioneer of the electrical propulsion: he electrified London Underground in 1890 and installed overhead tramways in Liverpool and Birmingham. His 1896 electric bus featured a series/parallel motor control system and hydraulic brakes.

Figure 4. Electric car by Thomas Parker, 1884 (source http://www.telegraph.co.uk)

Figure 5. Electric tricycle by Magnus Volk, 1888 (source http://endless-sphere.com)

An electric car powered by 28 cells and able to run at a good 13 km/h was built in 1886 by Ward Radcliffe and two years later Magnus Volk (1851–1937), a British engineer of German descent, had some success with his electric tricycle (Fig. 5). He became famous later for building railways, particularly the Brighton and Rottingdean Seashore Electric Railway along the coast of the English Channel that was in service between 1896 and 1901. In the same 1888 Immisch & Company of London built an electrical four passengers dos-à-dos dogcart which was belt driven by an Immisch motor. Established in 1882, the company was led by Moritz Immisch (1838-1903), an Anglo-German who was in business with Volk. In 1889 the London Electric Cab Company started a regular taxi service with 3 HP cars which boasted fast exchange for their 40 cell batteries and other advanced features. But the enterprise ceased two years later, burdened with a number of technical problems, including excessive battery weight.

B. *French- Belgian electrics*

The development of electrics was much more impressive in French. As early as 1881 French electrician Gustave Trouvé (1839-1902) presented at the first Paris Exposition Internationale d'Électricité an electrical tricycle powered by a Faure's battery, while Charles Jeantaud (1843-1906) built his first electric vehicle using a Gramme motor and a similar battery. A few years later a number of pioneers were making the first commercial electrical cars. They were conceived as carriages whose horses had been replaced with electric motors, so that they looked like horseless carriages. It was a common aspect of the self-propelled vehicles of the day since no dedicated automobile arrangement had yet been conceived.

Belgian gun maker Pieper started constructing electric carriages in 1889 and his son Henri in 1896 made the Auto-Mixte, the first known parallel hybrid car, which was able to operate in one mode at a time. The first commercially successful electric, able to carry six passengers at 16 km/h, was made in 1893 by Paul Pouchain. Jeantaud produced electrical cars from 1893 to 1906 and Louis Antoine Krieger (1868-1951) of Paris from 1894 (Fig. 6). The latter introduced the first regenerative braking system, i.e. electromagnetic braking with energy recovery, a solution under development in many present programs on electric cars.

Figure 6. A France made Krieger electric landaulet in Washington, D.C., circa 1906, owned by senator George P. Wetmore (Courtesy of Library of Congress, Prints & Photographs Division.)

The early electric car producers raced in a series of competitions, mainly in France, which promoted major technical improvements. On 18 December 1898 an electric Jeantaud Duc driven at 63.13 km/h by French car racer Gaston de Chasseloup-Laubat (1867-1903) set the first official land speed record. A series of records were then broken within a few months by Gaston and his rival Belgian Camille Jenatzy (1868-1913), who on 29 April 1899 drove his missile-shaped electric Jamais Contente (Never Satisfied) at 105.88 km/h (Fig. 7). That was the first time ever a land vehicle broke the 100 km/h barrier. The final aim of those races was to galvanize and conquer the rising market of individual self-propelled cars. In the age of positivism the wealthy class of the Belle Époque was allured by those devices powered by electricity, the dominant high–tech of the time, and capable to run much faster than horses and even steam locomotive. France soon became the largest automobile maker in the world, and was surpassed by the US only in 1904.

Figure 7. Camille Jenatzy with his wife on the victory parade on 1 May 1899 after the 100 km/h record-breaking run on 29 April 1899 (source Wikimedia Commons.)

C. Gernam electrics

Remarkably, electrical cars were retarded in Germany, where the leading electrical company, Siemens & Halske, was promoting public rather than individual transportation. At the 1879 Berlin Industrial Exhibition they presented the first effective electrical tramway, capable of transporting 6 passengers. Based on their efficient drum-type DC motors of 1872 (2.2 kW, 150 V, fed by the rails), it forerun the world's first operative electrical streetcar line (7.5 kW, 180 V, 2.5 km) that was put into service in 1881 in Lichterfelde, near Berlin. The following year the first overhead trolleybus became operational in Halensee, another Berlin suburb.

For individual self-propelled cars, at that time Germans engineers seemed more interested in ICE motors. After the first prototype gasoline car made in 1870 by Siegfried Marcus (1831-1898), in 1885 Karl Friederich Benz (1844-1929) built the first vehicle specifically designed for an ICE motor, actually a tricycle very similar to a horseless dogcart. It was followed by a bike (1885) and a four wheel car (1886), both by Gottlieb Daimler (1834-1900). It was only in 1899 that Austrian celebrated engineer Ferdinand Porsche (1875-1951) built an electric. It was his first automobile and featured very advanced solutions, with a hub-motor at each driving wheel (Fig. 8). Three years later he presented an innovative hybrid car with all four wheels electrically driven.

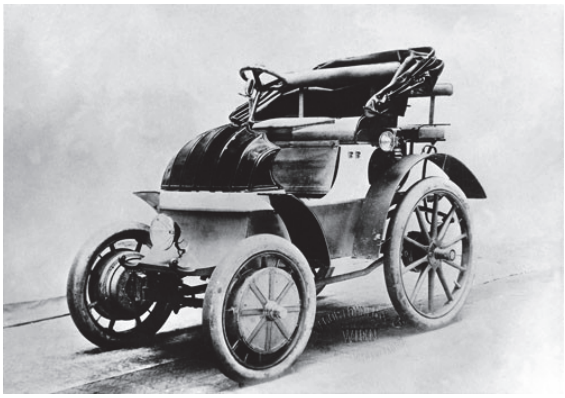

Figure 8. Ferdinand Porsche's electric car of 1899, with hub-motor at each driving wheel (source: http://stuttcars.com)

D. American electrics

Effective electrics in the US emerged a little later than in Europe. In 1884 Andrew L. Riker (1868-1930), then sixteen, made a naive electrical bike by providing a bicycle with an electric motor and a battery. Five years later he formed the Riker Motor Vehicle Company, one of the very first in America, which exploited his electric motors. Electric tricycles were built in 1886 by N. S. Possons of Cleveland for the Brush Electric Co (OH) to demonstrate their improved rechargeable lead acid battery, and in 1888 by Philip Pratt of Boston (MA). The first successful US four wheeled electric car, capable of transporting 6 passengers at 22 km/h, was made in 1890 by William Morrison, in Des Moines (IA), using his lead battery (Fig. 9).

Figure 9. First successful US electric car by William Morrison, 1890 (source: http://greenopolis.com)

The 1893 World's Columbian Exposition in Chicago decreed the success of electricity in America and paved the way to the expansion of the electric car market in the following two decades, while the first American car races attracted public interest. The growth of the US industry was then impressive, boosted by the spread in the 1880s of Edison's DC commercial electric networks, which formed the infrastructure for recharging batteries.

A large number of electric car companies were established. In 1896 the Pope Manufacturing Co, the leading maker of bicycles, put on the market the first practical American electric car, designed by Hiram Percy Maxim (1869-1936). To exploit the growing market they formed the Electric Vehicle Company, which in 1897 introduced in New York and Philadelphia the first electric cab service of the US. By the turn of the century they were the first US manufacture of electric cars. Other major producers were Anthony Electric, Baker, Detroit, Studebaker, Columbia, Anderson, Bailey, Chapman, Rausch & Lang, Waverly, Woods, and Edison (Fig. 10). For this rising market the same Thomas Edison (1847-1931) developed the lighter alkaline nickel-iron battery in the first years of the twentieth century.

Figure 10. T. A. Edison with an electric car in 1913 (source Wikimedia Commons.)

VII. Peaking and decline

Around 1900-1910 electric cars reached the highest success. In America the steam car had captured 40% of the car market, the electric car 38%, and the gasoline car 22%. These three technologies had different pros and cons. The steam engine was well established, powerful, fast, and reliable, but suffered long start-up times (25-45 min), short range due to the need for water refilling and required skilled operators. Gasoline cars were noisy, smelly, unreliable, fickle, heavily vibrating, had gear changes difficult to operate, and were difficult and dangerous to crank-start. Conversely, electric cars were silent, odorless, reliable, simple to drive, and easy to start. They were suitable for women (they were often named "women's cars"), but were expensive, slow (24-32 km/h). They were also low ranging (30-60 km), even though the introduction of exchangeable battery service around 1910 alleviated the recharging problems.

At that time individual self-propelled cars were used on urban streets, which had started to be paved in the first half of the century in continental Europe and from the 1870s in the Great Britain and in the US. Electric cars were ideal for wealthy city customers who could afford to pay for luxurious electric vehicles more than twice the cost of gasoline cars. Henry Ford (1863-1947) for himself and his relatives chose three luxurious Detroit Electric cars and so did John Davison Rockefeller (1839-1937) for his wife. Electric cars reached peak production in 1912, when they could be priced at $1750-3000, against the $650 for a basic gasoline Ford Model T.

At that time the poor state of intercity roads prevented the transit of heavily motorized carriages. But later, while the car market was rapidly expanding, technological, economical and environmental conditions changed, too. By the 1920s paved highways started connecting American cities. The emergence of such easily passable long-distance roads promoted cars capable of greater ranges, while the discovery of large crude oil reserves in Texas, Oklahoma and California caused gasoline prices to fall, making competitive the operational cost of ICE cars. At the same time they became cheaper and cheaper. Starting from the original $850 of the 1908 base Model T, prices fell dramatically after Ford introduced the assembly lines: by 1915 his cars were priced from $440 and by 1916 from $360 (something like $7200 today). At the same time ICE vehicles became more reliable and comfortable, thanks to technological advancements. Eventually the problem of their difficult start was solved with the electric starter which was first applied to a Benz car in England in 1896 and was brought to full industrialization in the US by Charles Kettering in 1912, initially for a luxurious Cadillac.

VIII. Conclusions

Thus, it was an electrical device that allowed ICE cars to fully spread throughout the market and finally overwhelm electrics. After 1920 electric vehicles gradually disappeared, remaining still popular for limited range services such as golf carts in the US and milk delivery in Great Britain. Their revival had to wait at least half a century.

References

[1] Precy Dunsheath: *A History of Electric Power Engineering*, Cambridge, MA: The M.I.T. Press, 1976.

[2] E. H. Wakefield, *History of the Electric Automobile Hybrid Electric Vehicles*, Washington DC: SAE International, 1998.

[3] D. Kirsch, *The Electric Vehicle and the Burden of History*, Piscataway Township NJ: Rutgers University Press, 2000.

[4] G. Mom, *The Electric Vehicle: Technology and Expectations in the Automobile Age*, New York NY: Johns Hopkins University Press, 2004.

[5] C. D. Anderson, J. Anderson, *Electric and Hybrid Cars: A History*, Jefferson NC: McFarland & C., 2004.