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The Dynamic Wireless Power Transfer Project: the Experimental Development of an Innovative Technology towards the Decarbonisation of Transportation Systems

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Abstract. In the recent years, with the rapid development of electric vehicles, the design and evaluation of different solutions for recharging these vehicles have been the subject of numerous studies. Dynamic inductive charging appears as a promising charging solution, offering several advantages: no physical connection with the vehicle, no manipulation by the user during charging, and reduced risk of damage and vandalism of the system. The research path followed two lines of experimentation. One on a large scale which consists of construction of a test track called "Arena del Futuro", equipped with Dynamic Wireless Power Transfer technology; the track is designed to test new materials and power system solutions aimed at research and system optimization. The other, on a small scale, sees the reproduction of the same technology used in the real circuit, but in the controlled laboratory environment where each variable, that makes up the complex system, can be modified.

Keywords: Electric Roads, DWPT (Dynamic Wireless Power Transfer), Electromagnetic Flux, Inductive Load

1 Introduction

In this article it will be reported the main points concerning the field experimentation, on a real scale, and the reproduction of the system on a small laboratory scale in order to manipulate the organization of the variables and investigate as many possible operating scenarios. Each test environment has been indispensable for the conduct analysis and the development of results necessary for the resolution of problems and the improvement of the complex system of electric roads and functioning with the Dynamic Wireless Power Transfer (DWPT) technology. From the on-site experimentation it was possible to obtain the efficiency of the electrical system in terms of energy transmitted to the vehicle and the quality parameters of the materials used for the construction of the circuit. Instead, in the experimentation reproduced in the laboratory, it was possible to test several types of materials at the same time and to investigate at every single moment which were the best options for the materials used by studying the progress of the aging of the single materials used on the track. This has a double advantage: the first is the timely and economical understanding, resolution and management of problems generated by the operation of a completely new system on site, the second is the possibility of testing as many alternatives as possible at the same time allowing to speed up the times of research and development. Obviously, the main goal of the experimentation aims to identify how to improve or change the system components to obtain maximum efficiency in terms of recharging of electric vehicles and durability of the road pavement [1]. The system will be ensured with advanced 5G connectivity in order to guarantee maximum road safety and V2I communications.

2 Experimental Programs

The development of this project saw the implementation of 2 guidelines of experimentation followed for the development of the research. Each of the 2 lines was complementary to the development of the other and of the system as a whole.

One is on site, which sees the construction of a test track 1km long and composed of different cross sections for the study of the behavior of the pavement applied to different urban and extra urban contexts. The other instead, carried out on a controlled scale in the laboratory, has made it possible to solve and develop complex problems with an evident economic advantage and speed of analysis. The laboratory experimentation also made it possible to develop an aging model of material subjected to the inductive load generated by the DWPT system and to study multiple additives in the same period of tests.

2.1 Large Scale Experimentation

The large-scale experimentation involved the construction of 1 km long track, with a ring-like plan shape, powered by 1 MW and to allows vehicles to sustain speeds up to 100 km/h. To test as many possible applications as possible, the circuit is composed along its length by 7 types of road cross sections differing in the thickness of the layers, granulometric curves used for the mix designs and types of innovative additives used to increase the performance of the bituminous conglomerate. Each section refers to different road types (Table 1). The purpose is to analyze the behavior of the system in terms of efficiency on different types of road network. The goal of the ring asphalt pavement construction is to study the interaction of the multiple variables that make up the DWPT system [2]. Once the study regarding the installations (power supply, distribution, and electromagnetic field protection) has been completed, the definition of the infrastructure in terms of the interaction of asphalt materials with EMFs is continued.

Table 1. Typologies of transversal sections constituting the pavement of the road ring (DP: drainage pavement; CP: closed pavement; MA: modified asphalt; UA: unmodified asphalt; IG: induction grout; S: sheath)

Section	Wearing Layer	Binder Layer	Upper Installation Layer
1	DP, MA	MA	IG, S

2	DP, MA	MA	S
3	DP, MA	MA	-
4	CP, MA	MA	IG, S
5	CP, MA	MA	-
6	CP, UA	UA	S
7	CP, UA	UA	-

The bitumen used for the mixtures is a modified hard with added fibers and innovative antioxidant additives in order to be able to ensure controlled aging under the inductive load of electromagnetic fields. The effect of electromagnetic flux results in a deupaperation of the chemical bonds characterizing the bituminous binder [3]. Currently, data is being collected that, as far as the mechanical behavior of the various types of pavements (shown in Table 1) subjected to the electromagnetic field, will be as follows:
- sampling of pavement cores for each type of cross section and subjecting them to mechanical tests (Resilient Modulus, Creep Compliance, Indirect Traction, and Marshall Resistance);
- bitumen extracted with the aid of toluene (250 ml toluene for 300g asphalt mix) will be subjected to rheometric tests in order to derive Master Curves.

Specimen sampling will be scheduled quarterly.
Non-destructive tests such as the Following Weight Deflectometer are performed to obtain rapid measurements about the evolution of the physical and chemical characteristics and mechanical performance of the 8 cross sections making up the circuit.

Fig. 1. Trial field photography with vehicles on the road: Iveco Intercity Bus and Fiat 500 utility car; **Zoom Fig. 1.** Detail of a portion of the ring track pavement where the electromagnetic coil used for wireless charging is visible.

Therefore, since to the test ring circuit has been completed both from the point of view of civil infrastructure and electric power system works and it is ready to face the testing phase, the installation of measuring systems for the detection of electrical quantities (voltage, power, current, etc.) are measured with appositive devices. The tests are carried out with all-electric vehicles New Fiat 500 and an Iveco Intercity bus (Figure 1). Power transfer occurs between transmitting coils located under the road surface, specifically in a protective grout box located below the road paving package made up of the binder and wearing layer, and receiving coils installed onboard the vehicles. Each coil can transmit a power up to 40 kW, so the total power received by the vehicle depend on the number of receiving coils with which it is equipped. The transmitting coils are powered only when a vehicle passes above through Management Units (MUs) placed beside the road. Every MU contains inverters for converting DC into high-frequency current needed to ensure a good coupling and high-power transmission efficiency. The measurements and analyses are performed both on the plant and infrastructural side, as well as in terms of overall system efficiency with devices positioned on the prototype vehicles circulating during the tests on the track (Figure 2).

Fig. 2. Measurement of magnetic field on board of the vehicle (left) and measurement system of electric quantities in the correspondence of MU and in AC/DC substation (right)

The data is acquired thanks continuous measuring devices. To calculate the efficiency of the system, which today reaches the 92%, it was decided to fix 80 meters straight section inside the circuit. The prototypes vehicles arrive at the straight section in acceleration, then move to a constant average speed and end the section in deceleration. The consumed and stored energy values are obtained as an average (Table 2).

Table 2. Energy consumed and stored by the prototype vehicles on the road test ring.

Vehicle	Speed [km/h]	Energy Consumed for 1 km [kWh]	Energy Stored for 1 km [kWh]
Bus Iveco	70/80	1.3/1.5	1.1/0.9
Fiat 500 car	70/100	0.16/0.2	0.35/0.25

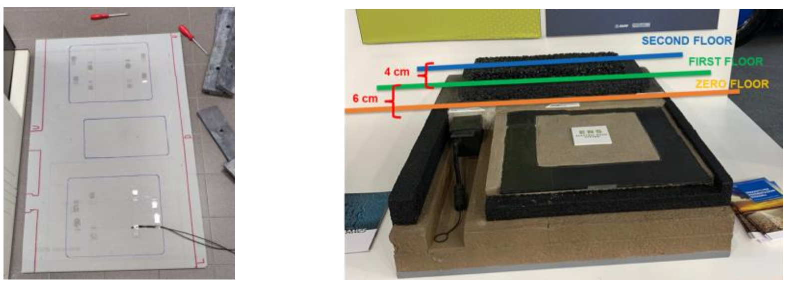
2.2 Small Scale Experimentation

In the laboratory, the line of work followed for the experimentation was different and focused on the research of materials and the evolution of their chemical, physical and mechanical properties following the time of exposure to the electromagnetic flux. To achieve this, a special experimental protocol was designed. It starts from the calibration of the same wave frequency of the electromagnetic field that is generated by the coils in the real circuit up to the elaboration and construction of an apparatus for measuring the fundamental variables which discriminate the quality and the efficiency of the system operation. An identical coil, to the one placed on site, is put into operation thanks to instrumentations capable of reproducing the same working pattern as a MU. First of all, a working direct current power supply with requirements of 50 V and 50 A feeds a wave generator which drives the wave frequency at which the coil must work. Subsequently, a second minor power supply, called coil controller, was connected directly to the coil and governs the correct functioning and the exact wave frequency generated. Therefore, the task of the coil controller is to modular the power of the electromagnetic flux to perfectly reproduce the conditions generated on site, in a stable manner and without loss of efficiency (Figure 3).

Fig. 3. Instrumentation and scheme of work for the reproduction of the DWPT system in the laboratory

To check that the assumption occurs, sensors have been positioned. Magnetic field sensors capture the trend of the electromagnetic flux in the space and temperature sensors detect the overheating of the system due to the operation of the coil components. A structure in non-magnetic material, to avoid the creation of disturbance effects or interference with the electromagnetic field, was then mounted above the coil (Figure 4).

Fig. 4. Preparation of the floors of non-magnetic structure to place specimens.



On the right of Figure 4 there is a picture showing a section of the roads package with the bins in which the coil and wiring are located. The colored lines shown indicate the levels at which the floor will be mounted, useful for positioning the samples of materials that will be subjected to aging due to inductive load during the experimentation in the laboratory. On the left there is a picture illustrating the preparation phases of the floors, these are made with a-magnetic materials not only to avoid creating disturbances and interferences with the electromagnetic field generated, but plasterboard panel was chosen even such it is knows as a fireproof material in case of overheating of the coil and possible fire. Therefore, 8 sensors have been installed for each floor to capture the electromagnetic flux and a sensor to record the temperature; a fourth temperature sensor has been installed in the test environment room.

Following the preparation of the plasterboard structure, samples of bitumen and bituminous conglomerate are then positioned on the non-magnetic structure to study the evolution of the aging of the materials due to the effect of the magnetic field. The aging that is reproduced in the laboratory is clearly of the accelerated type as the coil is kept active 24h/7days; while, on site the coils work only when it happens the recognition of the metal mass of the vehicle and takes place the communication between the source device, the coil, and the receiving device, the vehicle battery.

3 Expected Outcomes results and conclusion

The project is currently under patent and many of the most interesting results obtained cannot be published yet. Despite this, on site, thanks to the simultaneous experimentation carried out in the laboratory, it has already been possible to reach 92% of the efficiency of the system by making the utility car and the Intercity bus travel at an average speed of 80 km/h and 60 km/h respectively. One of the next research objectives will be to try to develop a functional calculation model to derive the aging due to the inductive load of the electromagnetic flux on road materials by setting the main variables: the frequency of the electromagnetic wave and the temperature generated by the functioning of the system [4].

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