STANDARD REVIEW – WIRELESS CHARGING OF THE ROBOT 'STEVIE'

Yann Blake – 17334432 – Group with E. R. Tighe and S. Dowd

Introduction

Trinity College Dublin is in active development of a service robot platform for applications involving social interaction with human users. The current prototype, nicknamed 'Stevie', integrates previous research in the areas of human-robot interaction, artificial intelligence, robot design and human-centrered design. [reference : tcd.ie]

The problem of our product today is: how to charge a service robot?

Several solutions have emerged from this: solar panels, high voltage line, classic connection to a socket, wireless charging. The solution and concept that seems most obvious to us is the wireless charging, removing from the robot user the constraint of connecting it regularly to a socket. For this we are thinking about the development of an inductive charging base station mat that would be permanently connected to power and on which the robot would position itself to charge.

Summary

The review is organized in four main sections reflecting types of standards: Fundamental standards, Product specification standards, Safety and Security standards and Test methods standards.

The main product specification standards concerning Wireless charging are Qi and AirFuel, from two competitors : the World Power Consortium and AirFuel group, which are industry standard groups. Qi standard have recently become internationally recognized thanks to the acceptation and promotion of IEC an international standards organization for all electrical, electronic and related technologies. The Qi wireless power transfer system power class 0 specification is therefore one to focus mostly on and describes all aspects of inductive charging including methods of placing the device on the surface called "Base Station". However AirFuel provides alternatives such as resonant technology for wireless charging or some solutions for larger device than what the Qi standard defines.

The European Union also provides many important safety standards for human exposure and other security matters, among which some are IEC or ISO (international) standards. In fact EN

standards uses some IEC standards so that it doesn't need to be rewritten and can follow internationally accepted standards.

Management System Standards describe the functions and structure/relationships within an organization This product would not require any such standards that would be specific.

Other standards for plugs and sockets, or the risk of slipping, and test methods are also detailed in this review.

1. Fundamental standards

A first type of standards that may apply to our product is fundamental standards. These can be symbols, signs, terminology or definitions. They are essential to make us understood during the different stages of our design process, and avoid confusion, misinterpretation or misunderstanding of the terms used. Especially since in the case of wireless charging, which is a very recent technology (the form that is used today dates from the 2000s [1]), and of which there are many alternatives, confusions can easily happen.

There is a particular ISO technical committee dealing with fundamental standards called ISO/ TC 37 and provides terminological knowledge engineering namely the tools to represent, manage and access knowledge of different degrees of complexity. [2] The ISO TC 37 Sc:3 is focusing on technologies and would be the most suitable for our project.

The Qi wireless power transfer system power class 0 specification IEC/PAS 63095:2017 also provides in its section 1.5 some definitions of terms and defines the acronyms and symbols specifically used in the case of inductive charging. For example : "*Base Station : A device that is able to provide near field inductive power as specified in The Qi Wireless Power Transfer System, Power Class 0 Specification. A Base Station carries a logo to visually indicate to a user that the Base Station complies with The Qi Wireless Power Transfer System, Power Class 0 Specification.*" Because this document explains the concept of inductive charging in its most precise aspects, all electrical acronyms are stated as follow : "*WPID : Wireless Power Identifier*" and symbols in the form : "f_{op} *: Operating Frequency [kHz]*". [3]

2. Product specification standards

The main type of standards we will have to deal with is product specification standards which defines characteristics of a product with performance thresholds.

The Qi wireless power transfer system power class 0 specification defines *"the interface between a Power Transmitter and a Power Receiver, i.e. Power Class 0 Base Stations and Mobile Devices.*

Power Class 0 is the WPC designation for flat-surface devices, such as chargers, mobile phones, tablets, cameras, and battery packs, in the Baseline Power Profile (≤ 5 W) and Extended Power Profile (≤ 15 W)."[3] We will then be confronted to a limit of power using the Qi inductive charging standard. The needs of the robot in terms of power will have to meet the ones described in the document. Also is it stated that these technology are more likely for "flat-surface device" which is obviously not the case of the robot Stevie. We will therefore have to analyze if the dimensions of the robot is compatible with this standard.

The Qi standard was originally developed by the Wireless Power Consortium an American multinational technology consortium in 2008 [4], and is since then promoted by the The International Electro-technical Commission (IEC), an international standards organization for all electrical, electronic and related technologies.

WPC details the methods of placing the device on the surface of the Base station: *"*Guided Positioning helps a user to properly place the Mobile Device on the surface of a Base Station. The Base Station provides power through a single or a few fixed locations on that surface. *Free Positioning enables arbitrary placement of the Mobile Device on the surface of a Base Station. The Base Station can provide power through any location on that surface.*"[3] This will be an important concern to determine the way the robot will be placed to the Base Station on the ground and how the robot will be able to achieve this on its own. From Mechanical to Electromagnetic and Thermal this standard defines many more specifications of the Qi wireless charging system.

The industry standard group AirFuel also developed their own standards for wireless charging. One of which is Rezence standard. Rezence use a different method for charging, namely resonant technology, which transmit power over long distances using a high frequency resonant tank of 6.78 MHz. The advantage of such technology is the ability to charge and support several devices simultaneous for up to 22W. Another standard is the Power Matters Alliance Standard (now part of Air Fuel Group) used by Duracell-Powermat for example, which is close to Qi standard, meaning that it uses inductive technology. These two standards are not internationally recognized for the moment, because of their very recent establishment. It remains that Qi standard is used much more for products that Air Fuel standards are. In fact, Qi is used by Asus, HTC, Huawei, LG Electronics, Motorola Mobility, Nokia, Samsung and Sony [5]. The reason could be that Qi standard have recently become internationally recognized thanks to the acceptation of IEC.

AirFuel has a good advantage for the case of a robot. As stated previously most of the standards for wireless charging concern small devices. A house-robot could potentially be over-sized to meet the requirements of some points among these standards. The advantages AirFuel brings is that, they have a strong partnership with Qualcomm a multinational company that designs and markets wireless telecommunications products and services. Qualcomm have recently developed an inductive charging road for electric cars. They designed a 100-meter test road with Vedecom. It incorporates a central strip in which is installed a dynamic electromagnetic induction non-contact charging system capable of recharging 20 kW at speeds up to 100 km/h. This energy transfer technology was originally developed by Qualcomm under the name Halo to integrate contactless chargers into electric car parking spaces [6]. Unfortunately we don't have access to the standards that they were using and respecting to develop this technology, the product having not been placed on the market, unless we contact them. Magne Charge was a similar but now obselete standard that was developed by General Motors in 2007.

Electromagnetic field (EMF) regulation for protection of the human body from exposure of the magnetic field from the inductive road charging is one of the important criteria in terms of safety. Just like electromagnetic interference (EMI) regulation, which is a critical requirement for electronic devices, EMF regulation is defined in most of the countries. In the application of mobile devices, the magnitude of current is in the range of a few amperes; however, the vehicle requires tens or hundreds of amperes and sometimes the coil with that current has several turns resulting in thousands of ampereturns.

However, shielding of the leakage magnetic field is a difficult problem when the frequency of the transfer power is as low as kHz and magnetic field is predominant. As the frequency is 20 kHz, the wavelength is about 15 km which is much longer than the dimension of the cable or vehicle, and therefore it is in the range of near-field. The shielding of magnetic field would be easier if the magnetic field is generated from a fixed structure; however, it is more difficult to block the magnetic field from the vehicle because it has to move with an air gap and the magnetic field passes through that air gap. Many solutions exist : *"The EMF can be minimized by active shielding with or without passive shields independently"[7]* The standards IEC 62110 and IEC 62110 define the magnetic field measurement method of electric systems ; and the average value of measurement at three points is reported as a final measurement by using active shield to calculate the leakage magnetic field.

The IEC TR 60083:2015 standard defines the plugs and socket-outlets for domestic and similar general use standardized in member countries of IEC. In the case where the product would be sold in Ireland, it will have to comply with type G, 230V 50Hz. [9]

3. Safety and security standards

It is obvious that a home robot, which is more likely to be for people who are sick or have reduced mobility, will have to comply with safety standards with respect to its users. Health concerns are therefore essential to take into account. The regulations governing human exposure must be considered and will concern our product. Products must be subject to the protection of the health and safety of harmful substances. Usually some independent organizations such as ICNIRP and IEEE [10] carry out experiments and investigations that are then used to define standards.

The harmonized standard EN 62233 applies to our project [11]. This International Standard deals with electromagnetic fields up to 300 GHz and defines methods for the evaluation of electric field magnitudes and magnetic flux densities around household electrical appliances. The safety of animals is also mentioned in this document "*Electrical equipment may be made available on the [European] Union market only if, having been constructed in accordance with good engineering practice in safety matters in force in the Union, it does not endanger the health and safety of persons and domestic animals, or property, when properly installed and maintained and used in applications for which it was made*." There is a large variety of obligations including when the product is placed on the market. The manufacturer is entailed to keep "*the EU declaration of conformity for 10 years after the electrical equipment has been placed on the market*".

The general standard IEC62311 has a close scope to the EN62233 : "*Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0Hz - 300GHz).*" The question arises of which one to focus on? The International Electrotechnical Commission (IEC) is an international body making standards specifically related to electro technical. Regional standard bodies such as the EU liaise with IEC in the standard preparation process. EN standards from the European Union (EU) can be about any domain. EN uses some IEC standards so that it doesn't need to be rewritten and can follow internationally accepted standards. [13]

Also the Institute of Electrical and Electronics Engineers a professional association of Engineers give more details on the basic restrictions for general public in their IEEE C95.1 2005 standard (equivalent to ICNIRP 1998 depending on the region where the product will be put on the market). For example the basic restrictions applying to various parts of the body for frequencies 3kHz-5MHz and 100kHz- 3Ghz is defined in the table above. Admittedly IEEE-SA is not a formal organization authorized by any government, whereas IEC is a recognized international standards organization.

		Action level[a]	Persons in controlled environments
Exposed tissue	f_e(Hz)	E_0 (rms) (V/m)	E_0 (rms) (V/m)
Brain	20	$5{,}89 \times 10^{-3}$	1.77×10^{-2}
Heart	167	0,943	0,943
Extremities	3350	2,10	2,10
Other tissues	3350	0,701	2,10

a. Within this frequency range the term "action level" is equivalent to the term "general public" in IEEE Std C95.6-2002.
E_0 is the rheobase in situ field. f_e is the frequency parameter.

NOTE Entries in Table 2 and elsewhere in this standard are sometimes given to three significant digits. This degree of precision is provided so that the reader can follow the various derivations and relationships presented in this standard, and does not imply that the numerical quantities are known to that precision

Electro Magnetic Compatibility (EMC) standards which regulate the allowed emissions of Electro Magnetic fields and require minimum immunity to them, may also apply. They can vary for use in specific environment such as medical environment. The world applicable standard for this is CISPR 14-1, CISPR 14-2 or for Europe only EMC directive/EN 55014-1, EN 55014-2.

The Qi Standard IEC/PAS 63095:2017 deals with heat risk which could lead to different fire hazard scenarios. In its section 11 the case of a Foreign Object placed on the Base Station is said to potentially raise the temperature depending on the object and the position of it : *"Such a temperature rise generally is due to eddy and/or induced currents that the Power Signal generates within the Foreign Object, and depends on the size, shape, material and surrounding properties of the Foreign Object, as well as on the strength and duration of the Power Signal."* [3] Various solutions are provided to avoid this danger further in the section, such as "*One method, for example, is to monitor the temperature of the Base Station Interface Surface for the occurrence of hot spots. Another possibility is to monitor the power loss across the interface between the Base Station and Mobile Device, based on the Received Power reported by the Mobile Device and the Base Station's knowledge of its Transmitted Power."[3]*

The Base station for wireless charging is expected to be placed on the ground. Some safety standards regarding. "*Slips, trips, and falls (STFs) are the leading cause of non-fatal, unintentional injuries treated in hospital emergency departments according to the All Injury Program*". The risk of slipping must therefore be considered seriously. The ISO and the Health and Safety Authority for Ireland [12] define the requirements to avoid the source of risk coming from the surface. The

“Walkway Safety: Introduction to Slip, Trip, and Fall Risk Control” report LB-30-10 from ISO defines the scope of slip, trip, and fall incidents.

The product will require from the user to use a socket and to be in contact with plugs, as well as electrical cables. Compliance with the requirements for electrical safety based on the standards EN 62311, EN 60950-1 or EN 62368 is therefore needed.

4. Test Methods

Last but not least, are the Test Methods standards. These are specifically designed to detail test and analysis methods for products. Test Methods standards therefore help to define and promote best practices. Some Test Methods standards were already stated in section *Product Specification standards*. The industry standard group AirFuel a competitor of the World Power Consortium (WPC) is offering a wireless-technology-based testing and certification program. “*The program consists of independent third-party testing by Authorized Test Labs followed by review and approval from our Certification Authority. They attest to compliance with the Conformance Test Specification, the Interoperability Test Specification, as well as satisfying the features and attributes necessary to ensure products and surfaces from different manufacturers are interoperable.*” [8]. This testing in based on the International Standards Organisation (ISO) standards: ISO 17065, ISO 17025 ILAC (for laboratories certification) and ISO/IEC 17025.

Considering that the product comes in the use of the domestic sphere, harmonized standards tests must be performed in accordance with the European Directives IN 60335-1 and EN 60335-2-6 providing for the household electrical appliances. [14]

Conclusion

This review identifies an important number of standards, organizes them in a hierarchy and highlights the specificity of each. It is important to take into account the fact that some standards have the same scope, and overlap each other, so we need to have some understanding of their obligations to determine which ones would suit to our product. Additionally, to know which of Qi or AirFuel standard would be most useful, it would require to go further in the design stages of the wireless charging system. It will nevertheless be important during this process to take into account all the European standards and IEC/ISO especially in terms of human exposure and risk of fire, highlighted in this review.

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