HEV-TCP TASK 26 WORKSHOP

MEETING 5: SAFETY OF WPT SYSTEMS

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HOSTED BY

HOLIDAY INN KNOXVILLE DOWNTOWN WORLD'S FAIR PARK
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Created in 1993, the activities of the TCP on Hybrid and Electric Vehicles (HEV TCP) are coordinated by the Working Party on Energy End-Use Technologies (EUWP). The aims of the HEV TCP are to produce and disseminate balanced, objective information about advanced electric, hybrid, and fuel cell vehicles. The HEV TCP accomplishes this through multilateral task-force projects. For further information on the HEV TCP see http://www.ieahev.org/. Views, findings, and publications of the HEV TCP do not necessarily represent the views or policies of the IEA Secretariat or of its individual member countries.

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1 Task Approach

Multilateral task-force projects within the TCP on Hybrid and Electric Vehicles (HEV TCP) are known as Tasks. Participation in a Task is an efficient way of increasing national knowledge, both with respect to the specific project objective and in terms of information exchange with peer institutions. Shared activity allows Task members to combine strengths, optimize resources, mitigate risk, and share knowledge.

1.1 Objective of Task 26

Task 26 aims to develop a greater global understanding of wireless power transfer (WPT) systems and interoperability through a focused study of WPT technologies being developed in the participating countries. This task includes a study of country-based standards (JARI, SAE, ISO/IEC), technical approaches, grid interactions, regulatory policy, and safety codes for WPT. The task will operate from Summer/Fall 2014 through May 2019 conducting two workshops per year, with each workshop focused on a particular aspect of wireless charging.

Participants in this task will benefit from their involvement. Some of the benefits of participation include;

- Broadening and deepening the expertise of automotive research organizations in WPT for electric vehicles (EVs) and related technologies.
- Strengthen working relationships and international collaborations.
- Access to information on research performed by other participants.
- Receive updates on recent developments in other countries.
- Remaining informed on the state of standards that may facilitate (or hinder) interoperability with WPT for EVs.

1.2 Focus of Workshop

Task 26 has conducted four previous workshops. The focus of this workshop was safety of wireless power transfer (WPT) systems. Speakers were sought with good insight into the technical, as well as practical challenges associated with the electromagnetic fields of wireless charging systems and the safety implications of these technologies. With the support from the task members we were able to review safety from various perspectives.

Workshop #	Month	Year	Focus	Location / Host
1	October	2014	Kickoff	Vancouver, BC – CANADA
2	May	2015	Leading Applications	Seoul, Korea / EVS 28
3	October	2015	Power Levels	Goteborg, Sweden / RISE Viktoria
4	June	2016	Interoperability & Standards	Rotterdam, The Netherlands / proov
5	**October**	**2016**	**Safety of Wireless Power Transfer Systems**	**Knoxville, TN U.S.A. / ORNL**

Figure 1. Task 26 Workshop Topics

2 Workshop Activities

2.1 Host Location

This workshop took place in Knoxville, Tenneesse in the United States. Our hosts for this event were Burak Ozpineci and Omer Onar of Oak Ridge National Laboratory (ORNL), Lee Slezak of the United States Department of Energy, and IEA's Technology Collaboration Programme on Hybrid Electric Vehicles (HEV TCP). This location was selected for co-locating the workshop with an IEEE conference focused on wireless charging and also for the proximity of Oak Ridge National Laboratory and the demonstration of their wireless charging system.

In 2015, the United States was listed as the world's second best-selling country market for PEVs according to HybridCars.com. The country's position is driven by policy, infrastructure, and vehicle availability. The U.S. government is promoting electric mobility by offering a federal incentive of 7,500 USD towards vehicles purchases. Additionally, at least 37 states and the District of Columbia have incentives such as high-occupancy vehicle lane exemptions, financial incentives, vehicle inspections or emissions test exemptions, parking incentives or utility rate reductions. As well as vehicle incentives to owners there are incentives to promote the construction of infrastructure, both public and private. At the end of 2015, there were a total of 13,730 charging stations across the United States, with over 30,000 charging outlets. A settlement in 2016 with Volkswagen will put an additional 2B USD towards EV charging over the next 10 years further expanding the infrastructure. The variety of options for plug-in vehicles continues to expand. During 2016, there were 30 PEV models sold in the U.S., which included 13 all-electric EV models and 17 plug-in hybrid EV (PHEV) models. At the end of 2016 Chevrolet began delivery of the much anticipated Bolt with a 238-mile range for an unsubsized sales price of 37,495 USD. Although the Tesla Model 3 with 215-mile range will not be available until 2017, the company recieved nearly 400,000 reservations by May 2016 for this vehicle priced at 35,000 USD.

2.2 Presentation Topics

With the support of the task members eight speakers were identified to present on safety of WPT systems. Presentations covered several areas of safety including field leakage, biological effects of magnetic field exposure, and foreign object detection.

Presentation	Contributor[1]	Affiliation
Pareto Fronts for Coils' Efficiency Versus Stray Magnetic Field in Inductive Power Transfer	**MING LU** and Khai Ngo	Virginia Tech
Characterisation of Influencing Factors on the Magnetic Leakage Field of a 7 kW Wireless Electric Vehicle Charging System	**LEANDRO PERCEBON**	Qualcomm
The Reality of Safety Concerns Relative to WPT Systems for Automotive Applications	Andrew Daga, John Miller, **BRUCE LONG**, and Peter Schrafel	Momentum Dynamics Corporation

[1] Contributor listed in **BOLD** was the presenter at the workshop.

Presentation	Contributor[1]	Affiliation
Development of an Exposure System of 85 kHzhz Magnetic Field for Evaluation Biological Effects	**KEIJI WADA**, Yukihisa Suzuki, and Akira Ushiyama	Tokyo Metropolitan University and National Institute of Public Health
Field Decay Characteristics of Wireless Power Transfer Emissions Over Earth Sites and in Semi-Anechoic Chambers	**NEVIN ALTUNYURT**	Ford Motor Company
ORNL Experiences and State-of- the-art Practices for Foreign Object Detection and Shielding	**OMER C. ONAR** and Madhu Chinthavali	ORNL
INL's Wireless Charging Testing Supports Code and Standards Development	**BARNEY CARLSON**	INL
Magnetic and Electric Field Emissions of IPT and CPT Systems in Electric Vehicle Charging Applications	Chris Mi and **FEI LU**	San Diego State University and University of Michigan

Figure 2. Safety of WPT Systems Presentations

2.3 Experts Panel Session

Given that this workshop was co-located with the IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW 2016) many experts in the field of inductive charging were on hand and willing to contribute to a more in depth discussion about the safety concerns surrounding these systems. Representatives from different parts of the transportation industry made up the panel that fielded questions regarding the safety aspects of wireless charging systems.

Panelist	Affliation
John Miller	Momentum Dynamics
Ted Bohn	Argonne National Laboratory
Khurram Afridi	University of Colorado
Veda Galigekere	Oak Ridge National Laboratory (formerly of Lear Corporation)

Figure 3. Panelist as part of the Safety Session

2.4 Demonstrations

As part of the workshop, attendees were given a tour of the National Transportation Research Center which is a component of ORNL. Of particular interest to participants was the facility's research and achievements with electric vehicle wireless charging systems. ORNL's Power Electronics and Electric Machinery Group developed a unique architecture that included an ORNL-built inverter, isolation transformer, vehicle-side electronics, and coupling technologies to realize the world's first 20 kW wireless charging system for passenger cars. Industry partners from Toyota, Cisco Systems, Evatran, and Clemson University International Center for Automotive Research also contributed to development of this charging system. For the demonstration, researchers integrated the single-converter system into an electric Toyota RAV4 equipped with an additional 10 kW-hour battery. System tests demonstrated greater than 90% efficiency.

The researchers are already looking ahead to their next target of 50 kW wireless charging, which would match the power levels of commercially available DC fast chargers. Providing the same speed with the convenience of wireless charging could increase consumer acceptance of electric vehicles, accelerate the adoption of electric vehicles and is considered a key enabler for hands-free, autonomous vehicles. Higher power levels are also essential for charging larger vehicles such as trucks and buses.

In addition to the static inductive tests, the wireless system at ORNL operates dynamically as well. The dynamic testing configuration is shown in the figure below. The laboratory setup includes two ground wireless coils with a peak WPT power of just over 9 kW with a car running through it at slow speeds. The team discovered that when the vehicle runs over both of the coils, while the first one is aligned with the vehicle side coil, the other one also interacts with the metal parts at the bottom of the vehicle reducing the power transfer peak.

Figure 4. Oak Ridge National Laboratory's 20-kW wireless charging system.

3 Key Findings

Based on the presentations, the panel discussion and the demonstration site visited, task members discussed the concerns about exposure to fields from these wireless charging systems. Health concerns are generally over thermal effects, electrostimulation, and effects on implanted medical devices. There are various organizations regulating the magnetic and electric field exposure limits. Among these, American Conference on Governmental Industrial Hygienists (ACGIH) define threshold limit value (TLV) and the biological exposure index (BEI) and these guidelines are mostly followed by the government organizations. IEEE and ANSI use the IEEE/ANSI C95.1-2005 for RF and Microwave frequencies (3 kHz to 300 GHz) which can be used for WPT systems. Furthermore, OSHA has the OSHA 29 CFR 1910.97 which is based on the 1966 ANSI standard (outdated). This OSHA requirement is only advisory and not regulated. Furthermore, ICNIRP guidelines limit the electric and magnetic field exposure for 0-300 GHz. SAE J2954 first adopted ICNIRP 2003 guidelines but then relaxed the limits to ICNIRP 2010 limits.

Limitations defined by ACGIH are given in Figure 5. Note that exposure values are spatially averaged over area equivalent to vertical cross section of human body.

Frequency	Electric Field Strength, E [V/m]	Magnetic Field Strength, H [A/m]
30 kHz-100 kHz	1842	163 [A/m] = 204.4 [µT]
100 kHz – 1 MHz	1842	163/f [A/m] = 204.4/f [µT]
1 MHz – 30 MHz	1842/f	163/f [A/m] = 204.4/f [µT]

Figure 5. Electric and magnetic field exposure limitations defined by ACGIH.

When the wavelength of the radiation is equal to the dimensions of the human body (1 to 2-meter range), then the efficiency of the absorption is maximized; requiring the lowest permitted exposures. E-field and H-field limitations as a function of the frequency (and wavelength) are given in Figure 6.

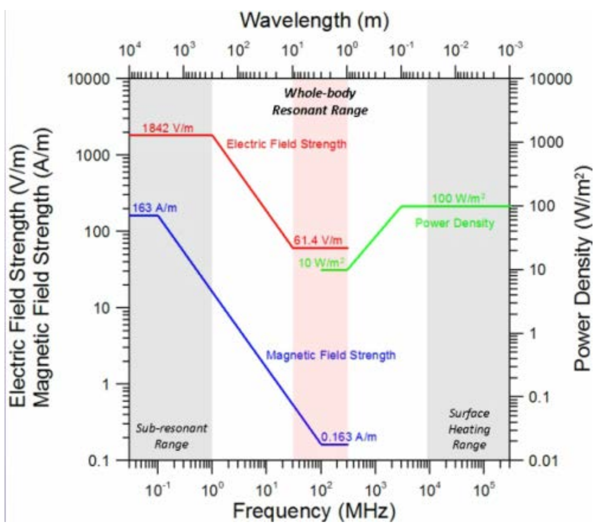

Figure 6. Electric and magnetic field exposure limitations as a function of frequency defined by ACGIH. Source: [ICNIRP guidelines](#).

IEEE Maximum Permissible Exposure (MPE) Limits for magnetic field (B-field) are given in Figure 7 for frequencies 3 kHz to 5 MHz which includes the frequency bands commonly used for WPT systems.

Frequency [kHz]	Action level (public exposure)		Persons in controlled areas (occupational exposure)	
	B_{rms} [mT]	H [A/m]	B_{rms} [mT]	H [A/m]
3.00-3.35	0.687/f	547/f	2.06/f	1640/f
3.35-5000	0.205	163	0.615	490

Figure 7. Maximum Permissible Exposure for exposure of head and torso: f = 3 kHz to 5 MHz

IEEE Maximum Permissible Exposure (MPE) Limits for electric field (B-field) are given in Figure 8 for frequencies 3 kHz to 100 kHz which includes the frequency bands commonly used for WPT systems.

Frequency [kHz]	Action level (public exposure)	Persons in controlled areas (occupational exposure)
	E_{rms} [V/m]	E_{rms} [V/m]
3.00-100	614	1842

Figure 8. MPE for exposure of head and torso: f = 3 kHz to 100 kHz

Limitations of the ICNIRP 2010 guidelines adopted also by SAE J2954 are given in Figure 9 whereas Figure 10 shows the limits when there is an implanted medical device or pacemaker in place.

Quantity	ICNIRP 2010 General Public Reference Level Regions 2 and 3 (Peak field strength)
Magnetic field	38.2 µT or 30.4 A/m (for 81.38 to 90 kHz)
Electric Field	117 V/m

Figure 9. EMF exposure standard: Reference levels

Quantity	ICNIRP 2010 Magnetic Field Limits for implanted medical devices / pacemakers Regions 2 and 3 (Peak field strength)
Magnetic field	21.2 µT or 16.9 A/m (for 81.38 to 90 kHz)

Figure 10. EMF exposure standard: Reference levels for implanted medical devices

The task members identified many issues with the safety of wireless charging systems that still need to be addressed. Those issues are listed below. The order of the points is not reflective of their importance.

- There is no internationally accepted standards on exposure limits. Both ICNIRP and IEEE have published recommendations. Blanket exceptions are made to ICNIRP 1998 for certain products or industries in Europe that wouldn't be possible it the United States if those standards applied. Denmark grid codes are based on IC standards but it basically applies only on the Transmission lines.
- Adoption of regulations will always be 4 to 5 years behind the actual release of guidelines. For example, Europeans abide by ICNIRP EMF guidelines released in 1998, although the latest version of the EMF guidelines was released in 2010. SAE J2954 references the 2010 guidelines.
- There is no information on secondary effects of EMF exposure to legacy vehicles.

- No information was presented about the heating effects of the EM fields on metals imbedded in a human body such as plates and screws in legs or imbedded devices such as pacemakers.
- These WPT systems are meant to function and not be seen. This presents a situation where there can be EMF exposure to people without their knowledge of the exposure.
- Should there be a concern around capacitive charging at 250 W and 5-6 MHz.
- The Federal Communications Commission operating in the United States considers a WPT system an intentional radiator due to its 85 kHz frequency. This requires that field strength be evaluated at 300 m from the source and within certain µV/m limits.
- WPT systems are being designed in a 'one size fits all' fashion as driven by OEMs but placement of the system on each vehicle can vary resulting in different field emissions under various configurations.
- Foreign object and living object detection needs to be done at lowcost using automotive qualified parts.

The members made several recommendations about how work in this area could help address these issues. Those ideas are listed below. The order of the points is not reflective of their importance.

- An international group should be brought together to look at the effects of electric and magnetic fields. This group should reach consensus and harmonize on these effects.
- Governments should agree to follow the body of evidence for WPT installations.
- Identify someone in the EU, Asia, and North America to look at additive field effects which will inevitably vary with the surroundings and with time. In addition to the wireless charging system the tire pressure sensor and keyless entry system are some other emitters around the vehicle.
- With help from OEMs and installers, develop the worst case scenario, recognizing that it will have an impact on cost.
- Researching which international organization should be oversight group for health effects of WPT.

4 Conclusions

In summary, the conclusions of the workshop are listed below. The order of the points is not reflective of their importance.

- More testing is necessary in the proper frequency and respresentative conditions to apply exposure limits to WPT installations.
- Identify appropriate medical group for standards on and effects on medical devices and initiate efforts to include them in future workshops.

5 References

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