

Effect of Road-Surface Water on the Electrical Characteristics of a Receiver Coil for Dynamic Wireless Power Transfer

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Abstract In Dynamic Wireless Power Transfer, deterioration of embedded transmitter coils due to water ingress has been reported, whereas its effect on receiver coils remains unclear. This paper investigates the influence of water on the electrical characteristics of receiver coils. Measurements showed that, with a transmitter coil, the internal resistance increased by 7.41% and the Q-factor decreased by 6.82%. Without a transmitter coil, only minor changes were observed. These results indicate that water on the road surface above the transmitter coil also affects the electrical characteristics of the receiver coil.

Keywords Dynamic Wireless Power Transfer, electrical characteristics, water, receiver coil

1. INTRODUCTION

Japan aims to achieve carbon neutrality by 2050, and the widespread adoption of electric vehicles (EVs) is being promoted as one means of achieving this goal. However, the share of EVs in new vehicle sales in Japan remains very low, and EV adoption has yet to progress significantly. Factors hindering the widespread adoption of EVs include limited driving range, long charging times, and insufficient charging speed.

Dynamic wireless power transfer (DWPT) has been investigated as a potential solution to these issues. DWPT is a technology that can eliminate the need for conventional charging and reduce the necessity of installing large-capacity batteries, thereby reducing the cost of EVs and extending their driving range. Consequently, DWPT has been actively studied in various countries.

In DWPT systems, transmitter coils need to be embedded in the road. For practical implementation, both mechanical and electrical characteristics are required. In terms of mechanical characteristics, the infrastructure must have durability comparable to or greater than that of conventional road pavement and provide adequate protection for the embedded coils. In terms of electrical characteristics, degradation of the coil characteristics caused by embedding and the long-term maintenance of the coil characteristics must be considered. However, it has been reported that embedding coils in roads can deteriorate their electrical characteristics ^{[1]–[8]}.

One possible cause of this deterioration is water ingress due to rainfall and other sources. In previous

studies conducted by our research group, water ingress into embedded transmitter coils and condensation inside the coils were observed. In addition, in our previous study, experiments were conducted using two types of transmitter coils: one wound with thread-covered Litz wire and the other using Litz wire covered with a waterproof coating. A certain amount of water was added to each coil, and the resulting changes in their electrical characteristics were investigated and compared. As the water content of the transmitter coils was gradually increased, deterioration of the electrical characteristics was observed for both types of coils. Furthermore, the use of a waterproof coating was found to reduce the deterioration of the coil electrical characteristics compared with the non-waterproof thread-covered Litz wire. It was also confirmed that passing current through the coil to generate heat and evaporate the water surrounding the coil was effective in improving the electrical characteristics of the transmitter coil. In addition, deterioration of the electrical characteristics of the receiver coil was also observed ^[9].

However, it was not possible to determine conclusively whether this deterioration of the receiver coil characteristics was caused by changes in the characteristics of the transmitter coil or directly by the water present on the transmitter coil. Therefore, it cannot be concluded solely from these results that the water on the transmitter coil caused the deterioration of the receiver coil electrical characteristics.

In this study, to investigate the extent to which water on the road surface affects the electrical characteristics of a receiver coil, measurements were conducted under two conditions: with and without a transmitter coil installed beneath the road surface.

2. EXPERIMENTAL METHODS

Four experimental cases were prepared and compared: Case 1, with a transmitter coil and a water film (Fig. 1); Case 2, with a transmitter coil and without a water film (Fig. 2); Case 3, without a transmitter coil and with a water film (Fig. 3); and Case 4, without a transmitter coil and without a water film (Fig. 4). The specifications of the transmitter and receiver coils used in the experiments are listed in Table 1.

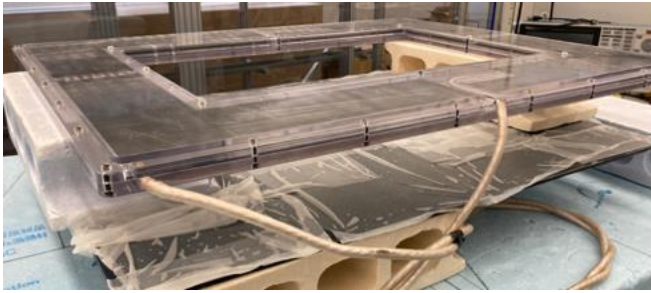


Fig.1 Water and Tx Coil (Case1)



Fig.2 No Water and Tx Coil (Case2)

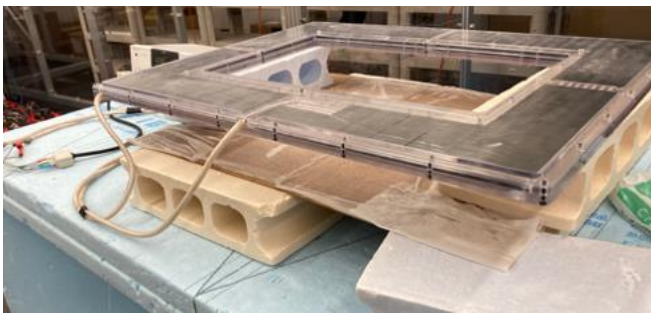


Fig.3 Water and No Tx Coil (Case3)



Fig.4 No Water and No Tx Coil (Case4)

Table.1 Design of Coils

	Transmitter coil	Receiver coil
Size	800×600 mm	800×600 mm
Turn	7	7
Pitch	24mm	11mm
Conductor Width	13mm	-
Diameter	-	7.85mm
Thickness	2mm	-
Remarks	-	Number of Strands 10000 Strand Diameter 0.05mm
Coil	Edge-Wise Coil	Litz-Wire Coil

An LCR meter (IM3536, HIOKI) was used for the measurements. The internal resistance, inductance, and Q-factor of each coil were measured at 85 kHz, which is the operating frequency used for DWPT. In addition, as shown in Figs. 1 and 2, the coupling coefficient between the transmitter and receiver coils was measured with and without a water film.

The coupling coefficient was measured using the open-short method. Specifically, the inductance of the transmitter coil was measured with the receiver coil placed directly above the transmitter coil in the open-circuit condition, denoted as L_{open} , and under the short-circuit condition, denoted as L_{short} . The

coupling coefficient was calculated by substituting these measured inductance values into Eq. (1). The distance between the transmitter and receiver coils was set to 100 mm.

$$k = \sqrt{1 - \frac{L_{short}}{L_{open}}} \quad (1)$$

3. EXPERIMENTAL RESULTS

The measurement results are shown in Tables 2, 3, and 4. Table 2 presents the results for Cases 1 and 2 and shows the measured electrical characteristics of the transmitter coil when it was installed. Similarly, Table 3 presents the measured electrical characteristics of the receiver coil when the transmitter coil was installed, corresponding to Cases 1 and 2. Table 4 presents the results for Cases 3 and 4 and shows the measured electrical characteristics of the receiver coil when the transmitter coil was not installed.

First, for Table 2, when a water film was formed on the transmitter coil, the internal resistance increased by 20.31%, while the Q-factor decreased by 16.80%. The inductance showed only a slight increase of 0.10%. In this study, an edgewise coil was used as the transmitter coil for experimental convenience. The results showed a trend like that observed in the authors' previous study described above.

Next, Table 3 shows the electrical characteristics of the receiver coil when the transmitter coil was installed. The internal resistance increased by 7.41%, the Q-factor decreased by 6.82%, and the inductance showed a slight increase of 0.05%. These results also showed a trend like that observed in the authors' previous study. The coupling coefficient between the transmitter and receiver coils with the transmitter coil installed was calculated using the open-short method by substituting the measured values into Eq. (1). The coupling coefficient was 0.404 both with and without the water film. This indicates that the coupling coefficient was not affected by the presence of water.

Finally, an analysis of Table 4 shows that when the transmitter coil was removed and a water film was placed on an insulating plate, the internal resistance of the receiver coil slightly decreased by 0.74%, while the Q-factor slightly increased by 0.74%. No change in inductance was observed.

Table.2 Change of Electrical Characteristics on Tx Coil (Case1,2)

Tx	Water	No Water
$R[m\Omega]$	83.05	69.03
$L[\mu H]$	39.81	39.77
Q	256	307.7

Table.3 Change of Electrical Characteristics on Rx Coil with Tx Coil (Case1,2)

Rx	Water/Tx	No Water /Tx
$R[m\Omega]$	74.22	69.1
$L[\mu H]$	96.02	95.97
Q	691	741.6

Table.4 Change of Electrical Characteristics on Rx Coil without Tx Coil (Case3,4)

Rx	Water /No Tx	No Water /No Tx
$R[m\Omega]$	53.48	53.88
$L[\mu H]$	96.24	96.24
Q	961.1	954

These results indicate that the receiver coil is not directly affected by the water present on the road surface. Rather, this suggests that the change in the electrical characteristics of the receiver coil is associated with the presence of the transmitter coil and its change in electrical characteristics due to the water film. In particular, the deterioration of the receiver coil characteristics is primarily associated with the increase in the equivalent series resistance of the transmitter coil. The receiver coil also exhibited deterioration only in its equivalent series resistance.

The effect of inductance on the electrical characteristics can be considered negligible because the rate of change in inductance was less than or equal to 0.10% for both the transmitter and receiver coils, as shown in Tables 2 and 3. The decrease in the Q-factor is attributed to its inverse relationship with the equivalent series resistance.

It should be noted that, strictly speaking, the "internal resistance" of the transmitter and receiver coils referred to in this study does not represent the

intrinsic resistance of the coils themselves. The value measured by the LCR meter corresponds to the equivalent series resistance (ESR). At present, it is unclear whether the intrinsic resistance of the coil itself increases due to the presence of water.

Furthermore, if the ESR increases due to water, it is necessary to investigate the physical mechanisms by which water causes this increase. These mechanisms will be investigated in future work.

4. CONCLUSION

In this study, the changes in the electrical characteristics of the receiver coil caused by a water film were investigated by comparing the cases with and without a transmitter coil. When the transmitter coil was installed, the presence of a water film increased the internal resistance of the receiver coil by 7.41%, decreased the Q-factor by 6.82%, and slightly increased the inductance by 0.05%. In contrast, when the transmitter coil was not installed, the presence of a water film slightly decreased the internal resistance by 0.74%, slightly increased the Q-factor by 0.74%, and caused no change in inductance.

These results indicate that the receiver coil is not directly affected by water on the road surface. Instead, the electrical characteristics of the transmitter coil are changed by the water on the road surface, which consequently causes changes in the electrical characteristics of the receiver coil.

As future work, the mechanism responsible for the changes in the electrical characteristics of the receiver coil, in addition to those of the transmitter coil, will be theoretically investigated. Furthermore, coil designs that can reduce the effects of water on the road surface will be studied.

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