

Prototype-less Development of Honda Smart Key System using Magnetic Field CAE

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ABSTRACT

In order to increase the development efficiency of smart key systems, a technology was developed that makes it possible to verify the mounting positions and key position detection performance of LF antennas in a short period and with no prototype vehicle using magnetic field CAE. A body model employed in collision CAE was simplified and the state of conduction in the vehicle was added in order to formulate body and seat models to study the magnetic field distribution inside and outside the vehicle, which changes in response to the body shape and the state of conduction between connected sections, at stages of vehicle development during which no prototype exists. The results of magnetic field CAE analysis and tests showed that it is possible to analyze the magnetic field produced by an LF antenna, which changes due to the effect of body shape and state of conduction, in a short period. In addition, a small, wireless electromagnetic sensor displaying stable measurement accuracy was developed, making it possible to increase analytic accuracy and boost the efficiency of studies. As a result, it is now possible to conduct smart key developments at the initial stage of new vehicle development, when no prototype vehicle exists.

1. Introduction

The diffusion of smart key systems has made it possible for users to conduct operations such as locking and unlocking the vehicle doors and starting up the power unit simply by carrying a key and operating a switch, with no need to insert a mechanical key into a keyhole. Honda commenced using smart key systems starting from the 2003 model Accord, and now uses the Honda Smart Key System in almost all of its vehicles.

Honda Smart Key detection employs the wireless communications shown in Fig. 1. Multiple low-frequency (LF) antennas are fitted inside and outside the vehicle (for example, in the center console and the door handles) in order to detect the position of the key.

When a high-frequency current is impressed in an LF antenna, a magnetic field is generated in the surrounding area. The strength of this magnetic field becomes attenuated in inverse proportion to the cube of the distance from the antenna. The key measures the strength of the magnetic fields produced by each of the LF antennas, and sends this information to the ECU fitted in the vehicle using radio waves in the ultra-high-frequency (UHF) band. Based on this information regarding the strength of the magnetic field, the ECU judges whether the key is inside or outside the vehicle.

When the ECU judges that the key is outside the vehicle,

it allows the vehicle doors to be locked or unlocked; when it judges that the key is inside the vehicle, it allows the power unit to be started.

Further, because the system is designed to only respond to a key that has been registered with the vehicle in advance, it also boosts vehicle security performance as an immobilizer. In addition, key position information can also be used for other functions that increase the convenience of the vehicle, for example Honda's Smart Welcome Lamp⁽¹⁾, which illuminates the door handles when the user

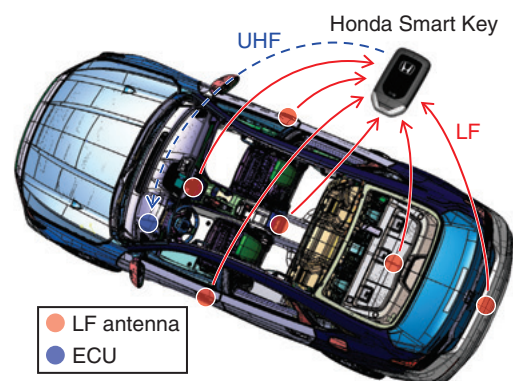


Fig. 1 Wireless communications in Honda Smart Key system

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approaches the vehicle (Fig. 2) and Hands-free Access Power Tail Gate⁽²⁾, which allows the tailgate to be opened and closed via the user's foot for hands-free access (Fig. 3).

At the same time, misdetection of the position of the key could result in the key being locked in the car or the power unit being mistakenly started, and it is, therefore, necessary to design the systems to accurately judge key position.

However, most vehicle bodies are constructed from conductive materials such as ferrous materials and aluminum alloys. The lines of magnetic force generated by the LF antenna have the property of curving under the influence of conductive materials, and the mode of diffusion of the magnetic field inside and outside the vehicle changes due to factors such as the vehicle design and the state of conduction between the conducting parts themselves.

Due to this, when developing smart key systems, it is necessary to determine the mounting positions for the LF antennas and verify key position detection performance in each new vehicle development. In addition, the same vehicle model might have different specifications; minivans, for example, are produced with specifications offering two rows of seats and specifications offering three rows of seats. In cases in which it is considered that the mode of diffusion of the magnetic field inside and outside the vehicle might be affected, it is necessary to conduct verifications for each specification.

Key position detection performance is verified at the initial stage of the new vehicle development process, using an existing mass production vehicle in which part of the structure has been modified. Since the vehicle design and

structure of the vehicle employed in verification and the new vehicle are different, verification is conducted again, but if the target detection performance is not obtained, it is necessary to change the design, including the design of peripheral parts, in order to change the mounting positions of the LF antennas.

Today, the use of prototype-less development^{(3), (4)} in order to shorten the development period has gained ground, and there are demands for the use of this method in the development of smart key systems. In order to make it possible to conduct prototype-less development of smart key systems, the research discussed in this paper, therefore, developed a simulation technology using magnetic field CAE able to evaluate the LF antenna mounting positions and key position detection performance at the initial stage of new vehicle development.

2. Development Aims

The following aims were set for the development of a simulation technology capable of prototype-less evaluation of smart key systems:

- (1) Ability to utilize data that can be obtained at the initial stage of new vehicle development.
- (2) Ability to evaluate LF antenna mounting positions and key position detection performance.
- (3) Ability to conduct calculations within a practical timeframe for developments for mass production.

3. Magnetic Field CAE Model

A model was developed for use in magnetic field CAE in order to analyze the magnetic fields produced inside and outside the vehicle by the LF antennas.

3.1. Body Model

Since the mode of diffusion of the magnetic field inside and outside the vehicle changes with differences in vehicle design, it would be necessary to formulate a body model for each new vehicle development. For the sake of efficient body model development, a body model used in collision CAE⁽⁵⁾ was employed as the base in the development of the magnetic field CAE model.

However, because collision CAE models are designed to reproduce the deformation of the vehicle body in a collision, the shape of each part is modeled in detail, and as a result, analytic calculations take time. In order to reduce the time necessary for calculations, the model was simplified by isolating only the elements necessary for magnetic field CAE analysis. In addition, the state of conduction between the conductive parts was also added to the model.

3.2. Seat Model

As in the case of the body model, the seat model was simplified by isolating only the elements necessary for magnetic field CAE analysis.



Fig. 2 Smart Welcome Lamp



Fig. 3 Power Tail Gate for hands-free access

When lines of magnetic force pass through a conductor with a loop structure, electromagnetic induction generates an induced current in the conductor. The lines of magnetic force are distorted by the magnetic field produced by this induced current, and this affects the magnetic field distribution. Due to this, the seats (which have a large and complex structure by comparison with other parts possessing conductive loop structures) have a considerable effect on the magnetic field distribution inside and outside the vehicle.

In addition, the state of conduction of the seat rails and the movable sections of the seats changes due to the effect of the position of the seats and the oxide films formed on the metal surfaces. The state of conduction between each of the seat frame components that forms the conductive loop structure of the seat was therefore added to the model.

3.3. LF Antenna Model

The LF antennas are approximately 60 mm in total length, and formed by winding coils around ferrite cores. The magnetic field CAE model reproduced the same shapes and electrical characteristics as an actual LF antenna, including the ferrite core dimensions and magnetic permeability, the number of coil windings, and the wire diameter and inductance.

In order to verify the ability of the model to reproduce the magnetic field distribution produced by the LF antennas mounted on the vehicle body, tests were conducted with LF antennas placed on metal plates, and the measurements were compared with the results of analysis using CAE. Assuming a scenario in which the key was on the floor of the vehicle, the results were compared for a position at a height 50 mm above the metal plate.

The market electromagnetic field simulation software CST Studio Suite and a general-purpose work station were employed in the magnetic field CAE analysis. The finite element method (FEM) was employed as the solution method.

Figure 4 shows the relationship between the strength of the magnetic field and distance from the LF antenna. Analytic deviation was a maximum of 8%. Converted into distance, this was smaller than the length of a single key, and it was judged that sufficient accuracy had been achieved to know whether a key is inside or outside the vehicle at the initial stage of development.

Figure 5 shows an example of analysis of the magnetic field distribution for an LF antenna mounted close to the center of the interior of the vehicle. The LF antenna was situated in the body model at the same position and angle as it would be in an actual vehicle, and the magnetic field distribution created by the LF antenna was analyzed.

The results showed that magnetic field CAE made it possible to study the uneven spread of the magnetic field generated by the LF antenna in the interior of the vehicle due to the effect of the seats and other conductive parts, and the shielding of the field by the vehicle body and the doors.

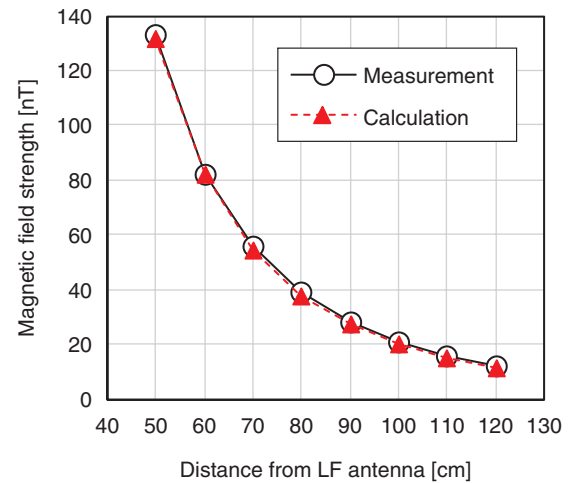


Fig. 4 Relationship between distance and magnetic field strength in measurement and CAE results

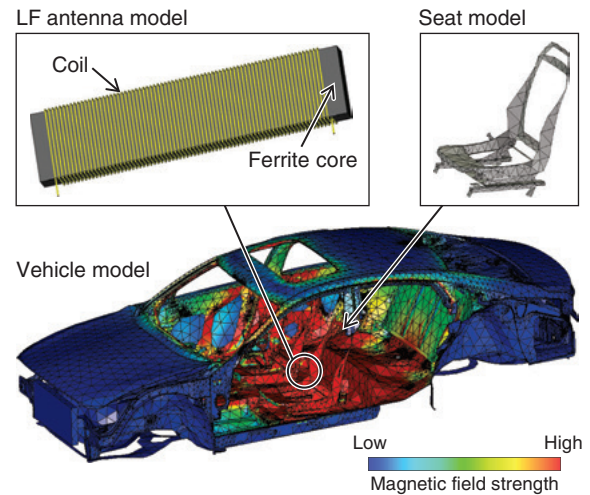


Fig. 5 Magnetic field analysis using CAE

4. Verification of Magnetic Field CAE

The effect of the conduction state of the seat frames on magnetic field distribution was studied using magnetic field CAE. In addition, the ability to reproduce the magnetic field distribution in an actual vehicle using magnetic field CAE was verified by comparing the results of measurements conducted in tests with CAE results.

4.1. Seat Employed in Tests

In order to determine the effect of the state of conduction of the seat frames on the magnetic field distribution, an experimental seat was created that made it possible to freely change the state of conduction between each of the seat

frame components (Fig. 6).

For the experimental seat, the main structure of a vehicle seat was isolated, and metals and resins of differing conductivity were selected as the materials employed in the joints between the seat frame components. A scenario in which the joints were all resin and the framework components were all insulated from each other was defined as completely non-conductive. Additionally, a scenario in which the joints were all metal and the framework components were all conductive was defined as completely conductive.

4.2. Development of Magnetic Field Sensor

It can be considered that the key may be placed in a narrow space, such as a cup holder or console box. Given this, it is necessary during the development of a smart key system to verify that the key position can be detected even when the key is located in a range of narrow areas in the vehicle.

A small wireless magnetic field sensor able to measure nano-tesla-order magnetic fields, of the same magnitude as that of the key, was, therefore, developed (Fig. 7).

In addition, it increased the efficiency of verification of analytic accuracy by clarifying measurement deviation due to factors including the measurement accuracy of the measurement device and the directivity of reception, as included in the measurement results.

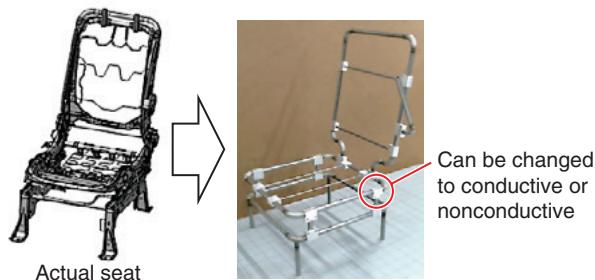


Fig. 6 Experimental seat

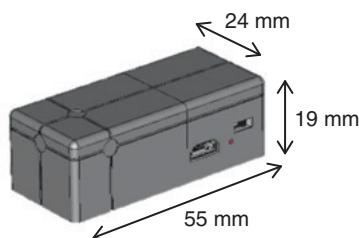


Fig. 7 Magnetic field sensor

4.3. Effect of Seat Frame on Magnetic Field Distribution

In order to determine the effect of the state of conduction of the seat frames on the magnetic field distribution, the magnetic field distribution was studied using magnetic field CAE when the state of conduction of the experimental seat was completely non-conductive and completely conductive.

The experimental seat and the LF antenna were positioned on a metal plate that simulated a vehicle floor panel. The completely non-conductive seat was insulated from the metal panel, while the completely conductive seat was conductive with the metal panel.

Figure 8 compares magnetic field distributions, analyzed using magnetic field CAE, for the completely non-conductive and completely conductive seats. In the case of the completely non-conductive seat, the magnetic field diffuses evenly, while diffusion is obstructed in the case of the completely conductive seat. These results confirmed that the magnetic field distribution changes due to the state of conduction of the seat frame.

In order to apply magnetic field CAE in development for mass production, it would be necessary to be able to detect the key position irrespective of the state of conduction of the seats. In order to consider the effect of the seat frame on the magnetic field distribution to the greatest extent possible, it was, therefore, decided to make the seat model completely conductive, and to also make the seat and the floor panel mutually conductive.

4.4. Reproduction of Magnetic Field Distribution inside Vehicle

The correlation between the analysis results and the measurement results was studied using an actual vehicle in order to verify the analytic accuracy of magnetic field CAE.

In order to determine the contribution of the state of conduction of the seat frame, the driver's seat was replaced by an experimental seat in a completely conductive state. At this time, the seat and the floor panel were also in a conductive state.

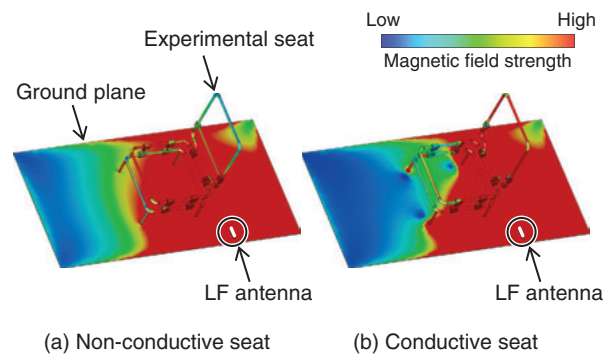


Fig. 8 Comparison of magnetic field distribution with conduction difference in seats

Figure 9 shows the results of measurements and CAE analysis of the magnetic field distribution produced by an LF antenna mounted close to the center of the interior of the vehicle.

Even when the measurement deviation of the magnetic field sensor is taken into consideration, the maximum deviation between the measurement and analysis results was 10%.

Converted into distance, this was smaller than the length of a single key, confirming that it was possible to detect the position of a key in an actual vehicle with a sufficient level of accuracy using magnetic field CAE.

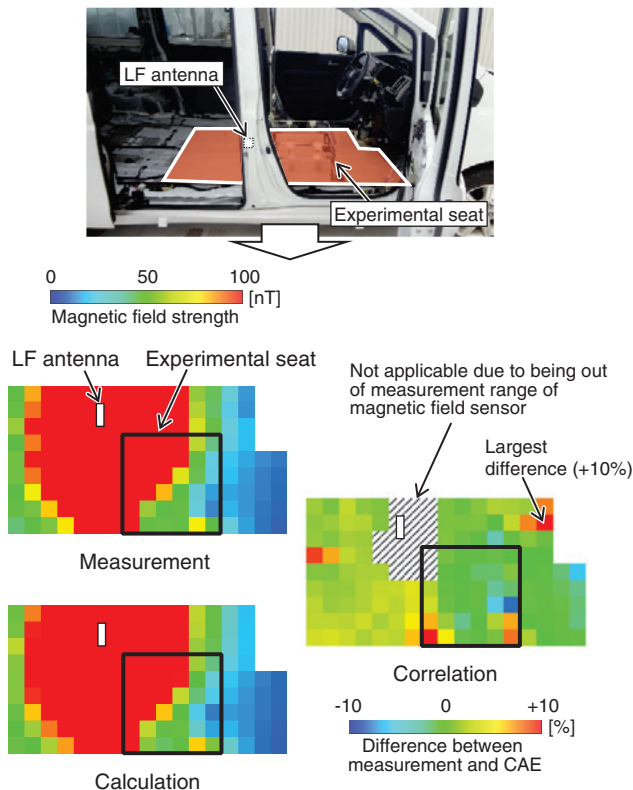


Fig. 9 Comparison of magnetic field distribution in measurement and CAE results for actual vehicle with experimental seat

5. Verification in Actual Vehicle

5.1. Study of Positioning of LF Antenna

This section will discuss an example of a study of the positioning of an LF antenna mounted inside a vehicle using magnetic field CAE.

Inside the vehicle, LF antennas are mounted on the instrument panel, the center console, and the trunk room, but in the case of sedans, because the structures in the vicinity of the trunk room are complex, key position

detection at the rear of the vehicle interior becomes an issue.

Magnetic field CAE was, therefore, used to study the performance of multiple LF antenna positioning proposals in key position detection at the rear of a sedan interior. Figure 10 shows the results of an analysis of the magnetic field distribution generated by an LF antenna positioned at the center console.

The analysis results indicate that only a slight difference in LF antenna mounting position changes the magnetic field distribution in the vicinity of the trunk room.

In this example, Proposal C, in which the magnetic field would diffuse uniformly towards the rear of the interior of the vehicle, was adopted in order to boost key detection performance at the rear of the vehicle interior.

Using magnetic field CAE, it was possible to study the positioning of LF antennas without evaluations employing an actual vehicle.

5.2. Key Position Detection Performance

Since the magnetic field distribution inside and outside the vehicle changes with the state of conduction of the seat frames, the realization of accurate key position detection under any seat frame conduction conditions becomes an issue.

A study was, therefore, conducted using a mass production minivan with three rows of seats in order to determine the effect of the seat frames on the magnetic field. In the interior of the vehicle, LF antennas were mounted in the instrument panel, on the floor close to the center of the vehicle interior, and in the cargo room.

Figure 11 shows measurement and analysis results for the magnetic field distribution inside and outside the vehicle

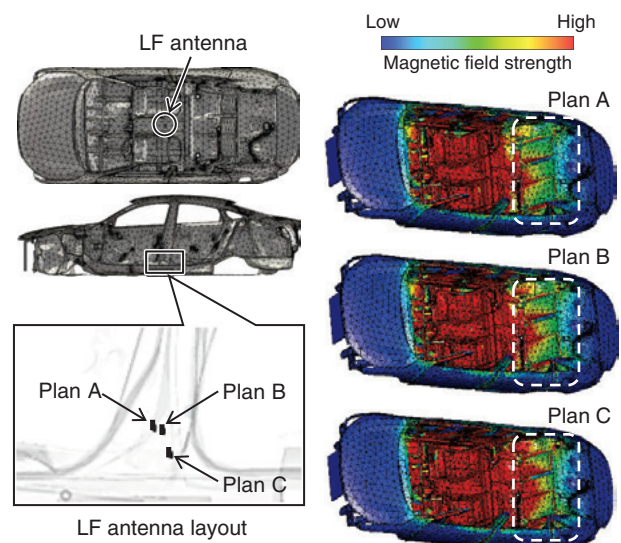


Fig. 10 Determining optimum layout from multiple antenna layouts

produced by an LF antenna positioned on the floor close to the center of the vehicle, where the effect due to the seats is greatest.

Figure 11(a) shows the distribution of the magnetic field that leaks to the outside of the vehicle. The results indicate that leakage is greatest from the gaps between the front and rear doors and the body, which are close to the LF antenna. The status of magnetic field distribution and the position at which leakage was greatest predicted by magnetic field CAE largely corresponded to the measurement results.

In order to realize accurate detection of key position outside the vehicle, the maximum value of leakage of the magnetic field obtained from magnetic field CAE was set as a reference value, and it was judged that a key position within a range in which the magnetic field was smaller than this reference value was outside the vehicle.

Figure 11(b) shows the magnetic field distribution inside the vehicle. A key position within a range in which the magnetic field was greater than this reference value

was judged to be inside the vehicle. The ranges, within which the keys were judged to be inside the vehicle, as predicted by magnetic field CAE largely corresponded to the measurement results.

These results verified that magnetic field CAE is capable of making predictions with a sufficient level of accuracy to conduct evaluations of key position detection performance at the initial stage of vehicle development.

5.3. Model Development Period and Calculation Time

A body model and seat model were formulated for magnetic field CAE using a body model for collision CAE during the development of a mass production four-door sedan. The total period for formulation of the models was approximately one month.

The calculation time for a model that positioned one LF antenna inside the vehicle was approximately five hours.

Since magnetic field CAE can be applied in analyses at the appropriate time following the study of mounting positions of the LF antennas, verifications can be conducted more efficiently than evaluations using an actual vehicle.

The results discussed above demonstrated that it is possible to evaluate smart key systems in a shorter period than evaluations using an actual vehicle by formulating magnetic field CAE models using data that can be obtained at the initial stage of development of new mass production vehicles.

6. Conclusion

A development technology for smart key systems able to be applied at the initial stage of vehicle development has been developed using magnetic field CAE.

The following is an overview of this development technology:

- (1) A technology was developed that allows the formulation of vehicle models from data available at the initial stage of vehicle development; these models make it possible to study the magnetic field distribution in a short period.
- (2) In order to verify the accuracy of the magnetic field CAE analysis, a small magnetic field sensor able to measure the magnetic fields inside and outside the vehicle with a known deviation was developed.
- (3) Studies using an experimental seat demonstrated that the state of conduction of the seat frames was the major factor of deviation in CAE analysis.
- (4) It was judged that it is possible to verify smart key systems using the results of analyses performed using magnetic field CAE.
- (5) It was verified that the new development technology could be applied in developments for mass production.

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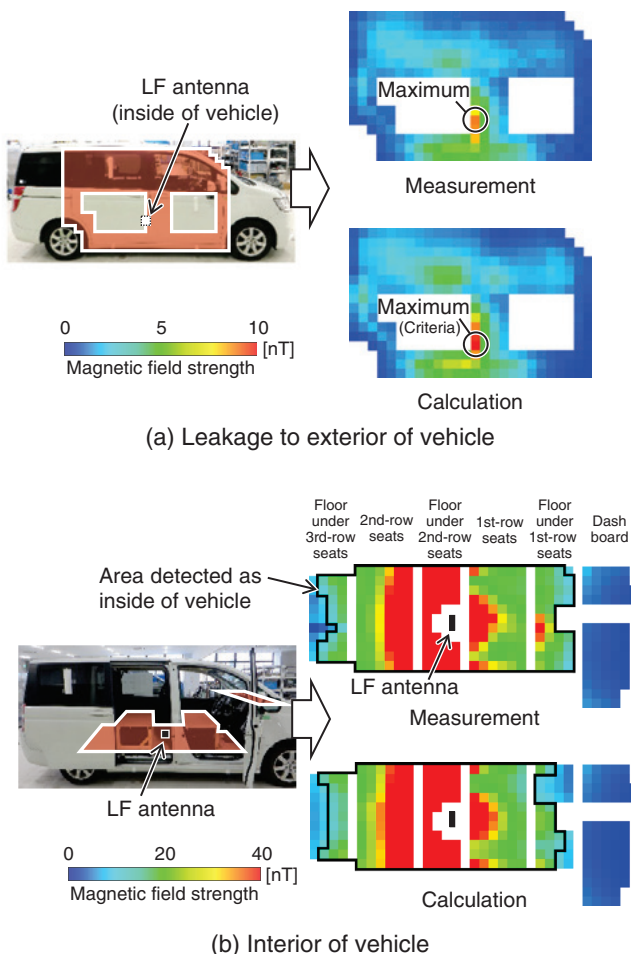


Fig. 11 Comparison of magnetic field distribution inside and outside mass production vehicle in measurement and CAE results

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