Shinkansen trains recognize information on their own position while running, and transponder ground coils are set up in intervals of approx. 3 km in order to correct that position information. Current position correcting ground coils (hereinafter, the “current ground coils”) are compatible with speeds of up to 350 km/h according to specifications, so speed that they are compatible with needs to be increased in order to cope with further Shinkansen speed increases.

Also, there have been cases of ground coils being damaged by blocks of snow falling from trains running at high speed in winter, so we are taking measures against snow damage in order to protect the front ends of ground coils. However, we have not been able to completely prevent damage, so ground coils resistant to snow damage are needed.

In this study, we conducted basic research to develop ground coils that can handle speed increases in excess of 350 km/h and that are resistant to snow damage.

Table 1 Specifications for Transmission between Ground Coil and Onboard Antenna

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission order</td>
<td>HLDC compliance</td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
</tr>
<tr>
<td>Ground coil → Onboard antenna (data)</td>
<td>1708±32kHz (Data 1: 1676 kHz, Data 0: 1740 kHz)</td>
</tr>
<tr>
<td>Onboard antenna → Ground coil (power)</td>
<td>757kHz</td>
</tr>
<tr>
<td>Message length</td>
<td></td>
</tr>
<tr>
<td>Ground coil → Onboard antenna (data)</td>
<td>80 (48) bits or greater Part in parentheses is information part</td>
</tr>
<tr>
<td>Modulation (transmission speed)</td>
<td></td>
</tr>
<tr>
<td>Ground coil → Onboard antenna (data)</td>
<td>FSK (64kbit/s)</td>
</tr>
<tr>
<td>Onboard antenna → Ground coil (power)</td>
<td>No modulation</td>
</tr>
</tbody>
</table>

2.1 Ground Coil Installation Position

Fig. 2 shows the installation position of current ground coils. The distance from top surface of rail to onboard antenna is 225 mm, and the top surface of the ground coil is within a range of 0 mm to 10 mm from the top surface of the rail. For that reason, the maximum distance from ground coil to onboard antenna is 235 mm.

2.2 Ground Coil Response Distance

Ground coils are supplied with electric power by power waves from onboard antennas, and messages are sent to the train when internal voltage reaches a certain level or greater. This range in...
which communications is possible from start to completion of transmission is called “response distance”, and Fig. 3 shows a conceptual diagram of that.

![Conceptual Diagram of Response Distance](image)

Ground coil response distance required according to train speed (V mm/s) is calculated by Formula (1), below.

\[
\text{Response distance} = V \times (\text{time required for transmission of five messages}) + 30 \text{ mm}
\]

- Four messages or more are required in the specifications, but five messages is set here to give leeway of one message.
- 30 mm was decided taking into account the distance traveled until ground coil internal voltage becomes stable.
- Fig. 4 shows the breakdown of time required for message transmission.

\[
\text{Response distance} = (1) \text{ Startup time} + (2) \text{ Message transmission time (approx. 1.4 ms) } \times 5 \text{ messages} + (3) \text{ Time between messages } \times 4
\]

![Breakdown of Time Required for Message Transmission](image)

Table 2 shows values of response distance calculated by Formula (1). The target speed for speed increase is set at 400 km/h to give a certain amount of leeway (current maximum speed is 320 km/h). In order to handle speed increases to 400 km/h, a calculated response distance of 962 mm is needed, and we found that response distance will need to be increased by 114 mm over that of the current specifications that handle 350 km/h.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Response distance (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 km/h (current specifications)</td>
<td>848 mm</td>
</tr>
<tr>
<td>400 km/h (handling speed increase)</td>
<td>962 mm</td>
</tr>
</tbody>
</table>

In order to identify actual values of current ground coils, we measured response distance and found the measured value of response distance to be 855 mm as shown in Table 3. Comparing that with the calculated response distance where speed of 350 km/h can be handled in Table 2, we found that current specifications were met but response distance is insufficient to handle increases in speed to 400 km/h (962 mm required).

<table>
<thead>
<tr>
<th>Compatible ground coil</th>
<th>Response distance (measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 km/h (current ground coil)</td>
<td>855 mm</td>
</tr>
</tbody>
</table>

Response distance needs to be increased to handle speed increases and methods for that are separated into those that follow current ground coil specifications and those whereby new specifications are developed.

3.1 Study Based on Current Specifications

Ordinarily, ground coils operate by induced electromotive force generated by receiving power supply by power waves from onboard antennas, so response distance of ground coils is greatly affected by internal voltage of ground coils. So, if a mechanism can be devised to generate internal voltage by means other than power waves, time until voltage becomes stable can be reduced and response distance thus increased. We therefore studied increasing response distance by supplying power from external sources.

Fig. 5 shows the configuration of a device used for verification. Voltage (5 V, equivalent to ground coils internal voltage) was constantly supplied from an external source and response distance measured.

![Configuration of Device Used for Verification](image)

Table 4 shows measured values of response distance with 5 V supplied. By supplying 5 V from an external source, response distance became 1,017 mm, an increase of 162 mm over that of current ground coils.

<table>
<thead>
<tr>
<th>Supplied voltage</th>
<th>Response distance (measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (current specifications)</td>
<td>855 mm</td>
</tr>
<tr>
<td>DC 5 V (external power supply/constant operation)</td>
<td>1017 mm</td>
</tr>
</tbody>
</table>

3.2 Study Based on New Specifications

Table 5 shows items changed in the new specifications to handle speed increases. We may be able to increase response distance by making ground coils and onboard antennas larger, but we would have to consider how and where to install them if doing so. The response distance required can be made smaller by changing the transmission system or message content to change the constants in Formula (1), but an increase in construction time and costs with modification of onboard antennas would need to be considered.
When trains run with snow built up in areas such as the bogies, blocks of snow accumulated may fall off while running due to vibration, temperature change, and the like. There have been many cases of snow falling from Shinkansen trains while running at high speed, damaging or scattering equipment.

Fig. 6 shows an example of a ground coil damaged by a falling block of snow. In this example, only part of the ground coil is damaged, but the entire ground coil and its fasteners may be damaged in some cases.

4.1 Current Countermeasures

Fig. 7 shows current countermeasures against snow damage on slab track. Assuming that a block of snow may strike in the direction a train travels, a triangular protective device is attached on the side of the ground coil that may be struck to reduce the impact of blocks of snow striking the ground coil.

Fig. 7 Countermeasures Against Snow Damage (Slab Track)

Fig. 8 shows current countermeasures against snow damage on ballasted track. Like with slab track, it is assumed that a block of snow may strike in the direction a train travels. A rubber block is attached to the front of the ground coil to reduce the impact of blocks of snow striking the ground coil.

Fig. 8 Countermeasures Against Snow Damage (Ballasted Track)

4.2 Enhancing Countermeasures with Speed Increases

Current countermeasures against snow damage demonstrate a certain level of effectiveness. However, falling blocks of snow at high-speed travel have the power to damage the protective devices and blocks, so damage to ground coils cannot be completely avoided. As kinetic energy is proportional to the square of speed, there is a fear of damage increasing with increases in Shinkansen speed.

In the countermeasures against snow studied this time, we adopted a policy of avoiding as much as possible being struck by blocks of snow having massive amounts of energy instead of protecting the front end. Fig. 9 shows an image of the new countermeasures against snow damage. To prevent ground coils from being struck by blocks of snow, the position where they are installed is lowered, which reduces the probability of being struck.

Fig. 9 Image of New Countermeasures Against Snow Damage

5 Investigation of Impact of Slabs

Most Shinkansen track is slab track, and wireless transmission between ground coils and onboard antennas may be adversely impacted by rebar in the slabs if the position of ground coils is lowered. We therefore investigated the impact of slabs.

5.1 Method of Testing Slabs

Slab tests were conducted on four types of slab (AF-57, A-51C, A-55M, AF-55C) at different locations using the two methods described below to measure. Measurements were made at the six locations in Fig. 10, with measurements made at projections from slabs and the center of holes of frame-shaped slabs in addition to the slab parts.

(1) Fix position of onboard antenna and measure while bringing ground coil closer to slab.
(2) With interval between onboard antenna and ground coil kept fixed at 235 mm, measure while bringing ground coil and onboard antenna closer to slab.

5.2 Results of Slab Tests

Results of measurement on a typical type of slab (A-55M) are shown as follows. Fig. 11 shows a graph of induced voltage at projections of the slab and at the center of the slab when position of the onboard antenna is fixed and the ground coil is brought closer.
closer to the slab. Voltage is lower at the center of the slab than at projections of the slab.

Fig. 12 shows a graph of the induced voltage at the projections of the A-55M slab and at its center when interval between onboard antenna and ground coil fixed at 235 mm and the ground coil is brought closer to the slab. Results were expected to show constant values if there was no impact from the surroundings because the interval is constant, but induced voltage dropped markedly as the ground coil was brought closer to the slab, particularly at the center of the slab. From this, we suppose that transmission is impacted by slabs, particularly at the center of the slab. Note that similar trends were seen regardless of the type of slab.

Thickness of concrete covering differs by type of slab, and Fig. 13 shows a graph of test results with distance between rebar and ground coil as the horizontal axis. At the center of the slab, induced voltage rapidly drops as the distance between rebar and ground coil becomes smaller. The same induced voltage as when the ground coil is attached at projections of the slab is seen when the distance is 260 mm or greater, so we discovered that there is almost no leeway at the center of the slab to lower the attachment position. On the other hand, no drop in induced voltage was seen at projections of the slab until about 175 mm between rebar and ground coil, so we discovered that there is leeway there to lower the attachment position.

6 Conclusion

In this research, we studied how to handle speed increases for new Shinkansen position correcting ground coils and countermeasures against snow damage. Results demonstrated a possibility of handling speed increases by supplying power from an external source or changing the ground coil size or communications system. For countermeasures against snow damage, results of investigation of the impact of lowering the attachment position compared with the current position revealed that impact of rebar in slabs is large at the center of the slab, making it difficult to lower the position there while impact is small at projections of the slab.

In the future, we plan to produce a prototype new position correcting ground coil to handle speed increases taking into account the results of these studies and investigations. We also plan to further study attachment positions in more detail.