Power Supply Technologies for Battery-Powered Trains

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KEY WORDS: **Wireless Power Transfer, Battery-Powered Train, Rail,** Other Means of Mobility [F3]

Battery-powered trains are attracting growing attention as a practical and economical option for decarbonizing non-electrified railway lines. While alternatives such as hydrogen-powered vehicles and biodiesel fuels are also being considered, these technologies are still developing, and full electrification is not always the best solution because of traffic demand, infrastructure cost, construction constraints, and interface conditions with existing electrified sections. By contrast, battery-powered trains can use existing electrified sections for charging while operating on onboard batteries in non-electrified areas, making them a realistic option for railway decarbonization.

The key issue is not only the onboard battery itself, but also the design of the power supply system. Battery-powered trains should be planned as an integrated system in which vehicle performance, charging infrastructure, and operation schedules are coordinated. Because railways operate on fixed routes and timetables, charging locations and durations can be planned more systematically than in road transport. At the same time, charging failures can directly affect punctuality and disrupt operation over an entire line. For this reason, robust and reliable charging systems are essential.

From the viewpoint of power supply design, four points are particularly important: where charging is performed, how much time is available, how much energy must be supplied, and whether stable operation can be maintained under abnormal conditions such as delays, long dwell times, battery degradation, severe weather, or charging failure. Among these, charging power is especially critical, because railway vehicles often need to receive large amounts of energy within short station dwell times. This requires high-power infrastructure and careful consideration of the interface between train and ground equipment, the receiving power environment, and the effect of rapid charging on battery life.

At present, most practical battery train systems rely on contact-based charging using conventional railway current collection technologies such as overhead contact lines, pantographs, or third rails. In many cases, these are combined with partial electrification or charging facilities installed at terminal or intermediate stations. This shows that battery-powered trains are not simply a vehicle technology, but a system solution based on an appropriate division of roles between onboard batteries and ground infrastructure.

As a future option, wireless power transfer (WPT) is also being studied for railway applications. Although WPT is currently less advantageous than contact-based systems in terms of cost per charging capacity, it offers unique benefits because it has no mechanical contact and can provide seamless power transfer from standstill to low-speed running. This makes it suitable as a supplementary charging technology, for example in stations, in low-speed sections near stations, or on steep gradients.

The Railway Technical Research Institute has been developing railway WPT systems based on magnetic coupling. A notable feature is the use of figure-eight shaped coils on both the ground and vehicle sides, which helps suppress losses caused by rails and wheelsets. Experimental studies have demonstrated the feasibility of high-power railway WPT, together with improvements in power density, coil gap, and efficiency. More recently, lower-frequency and even commercial-frequency concepts have also been investigated to reduce system cost and electromagnetic noise.

In summary, the introduction of battery-powered trains depends fundamentally on the design of the power supply system. Contact-based charging remains the practical mainstream, while WPT is a promising supplementary technology for future railway decarbonization.

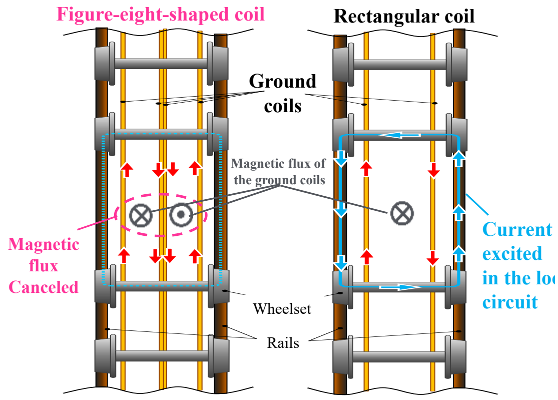

Fig.1. Advantages of the figure-eight-shaped coil

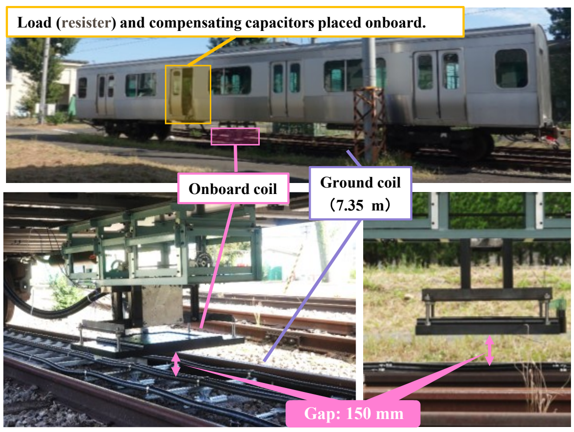

Fig. 2. Testing of the railway WPT system with improved power transfer density