Development of Compact Maintenance System for Railway Signalling Equipment using Multiplex System and FFT Analysis

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To ensure the safety of train operation, signalling equipment is installed along railway lines. For the maintenance of this equipment, a dedicated train called an “electric testing car” has been used. But this train is operated on the individual sections only twice a year and requires skill to analyze the collected data. Furthermore, the organizations of maintenance and surrounding environment are increasingly becoming difficult for railway companies in recent years. So we have developed a compact maintenance system that can be mounted on a commercial train and analyze data easily. In this paper, we explain the method of measuring signalling equipment, function of this system, and the results of field test.

Keywords: Multi-carrier wave, FFT analysis, Automatic Train Stop (ATS), Resonance frequency \((f_0)\), Radical degree \((Q)\)

1. Introduction

To ensure the safety of train operation, signalling equipment is installed along railway lines. A great deal of maintenance labor is required for the equipment. For example, Japan Railway Companies (JRs) have introduced the Automatic Train Stop (ATS) system into all line sections. We have to measure the resonance frequency \((f_0)\) and the radical degree \((Q)\) of ground coils for ATS. Moreover, we have to measure the track circuit current and the sensitivity of electronic train detectors for level crossing. By analyzing the measured data, we can prevent problems from occurring in that equipment.

For the maintenance of this signalling equipment, a dedicated train called an “electric testing car” has been used on JR lines. This train was made in the 1970s. It mounts sensors and processing parts for measuring various items separately, and these devices are extremely large in size. The running cost is high, because the train is a specialized one. It is operated on the individual sections only twice a year, and it takes skill to analyze and grade the collected data.

The organization of maintenance and surrounding environment is becoming increasingly difficult for railway companies in recent years and there is a great demand for a new maintenance system which can save labor and measure the signalling equipment more frequently. So we have developed a compact maintenance system that can be mounted on the underfloor plate of a commercial train.

The new system shares a single sensor to measure ground coils for ATS, track circuits and electronic train detectors for level crossing. Accordingly, a large space is not required for installation on an underfloor plate of a train. It refines the measuring method. The primary coil of the sensor can transmit a multi-carrier wave simultaneously, and the secondary coil can receive mixed multi-carrier wave induced by coupling with ground coils for ATS. This system calculates \(f_0\) and \(Q\) of ground coils by FFT analyzing mixed multi-carrier wave using a Digital Signal Processor (DSP). Using simultaneous multi-carrier wave and digital signal processing, it can measure signalling equipment precisely, if the train runs at high speed. Moreover, we can analyze the collected data easily and express the results of measurement graphically by the wayside analysis system.

In this paper, we explain a new method of measuring signalling equipment, construction and function of this system and the results of its field test.

2. Method of measuring ground coils for ATS

2.1 The 3 dB method and the phase method

A ground coil for ATS is composed of parallel resonance circuits using an inductor and a capacitor, and has the function to change \(f_0\) according to the aspect of the related signal. There are a 3 dB method and a phase method to measure \(f_0\) and \(Q\) of ground coils for ATS.

The 3 dB method is to calculate \(Q\) using \(f_0\), i.e., the frequency at the maximum voltage induced by coupling with ground coils, and the frequency at a voltage which declines by 3 dB from the maximum voltage. As shown in Fig.1, when the oscillator is connected with the primary coil of the sensor, a voltage is induced on its secondary coil by the resonance current of the ground coil. Moreover, when sweeping the frequency of the oscillator, the voltage induced on the secondary coil becomes maximum at \(f_0\) of the ground coil. By searching the frequencies \(f_1\) and \(f_2\) with the voltage which declines by 3 dB from the maximum voltage, it is calculated as \(Q=f_0/(f_2-f_1)\). This way has the advantage of measuring \(Q\) without being influenced by the shape of the ground coil (There are large-size and small-size ground coils for ATS on JR lines.). However, it is impossible to measure while the train is running at high speed.

On the other hand, the phase method uses a phase as
the means to specify the above-mentioned \( f_0 \), \( f_1 \) and \( f_2 \). The phase difference between the output voltage of the oscillator and the voltage induced on the secondary coil of the sensor becomes 90° at \( f_0 \). The phase difference also becomes 90° ± 45° at \( f_1 \) and \( f_2 \). In this way, we can calculate \( Q \) by substituting these \( f_0 \), \( f_1 \) and \( f_2 \) into the above-mentioned formula.

### 2.2 Method of measurement by the electric testing car

On the electric testing car, \( f_0 \) and \( Q \) of ground coils for ATS are measured by a simple technique. A special oscillator begins to oscillate at \( f_0 \) of the ground coil when the train approaches it. Because the oscillation frequency is the same as \( f_0 \) of the ground coil and the oscillation voltage is proportional to \( Q \), it is possible to obtain \( f_0 \) and \( Q \) of the ground coil by measuring the frequency and voltage of oscillation. In this way, it can measure at comparatively high precision using simple equipment, but there is the disadvantage of an error occurring in the measured \( Q \) mainly in changing the distance between the ground coil and the sensor.

### 2.3 Method of measurement by this new system

We will try to develop a new maintenance system for signalling equipment that can be mounted on the underfloor plate of a commercial train, to measure the ground coils for ATS precisely even when the train runs at high speed. Therefore, a way must be developed to realize the 3 dB method, on a high speed train, without much influence from the shape of the ground coil. So we contrived a method in which the primary coil of the sensor transmits a multi-carrier wave every 200 Hz between 97 kHz and 137 kHz except between 113 kHz and 119 kHz simultaneously by using the multiplex oscillator as shown in Fig. 2. The reason for excluding the frequency band between 113 kHz and 119 kHz is that it is not used as the resonance frequency of ground coils for JR’s ATS. For example, the resonance frequency of ground coils for JR’s ATS becomes 130 kHz or 123 kHz when the aspect of the signal orders the train to stop, and becomes 105 kHz when it allows the train to proceed. Thus without taking time to sweep frequencies, this method can measure the ground coil if the train runs at high speed. Moreover, the primary coil of the sensor transmits a single-carrier wave of 116 kHz for the pilot signal to revise the voltage induced on the secondary coil with the resonance current of the ground coil. As shown in Fig. 2, the measurement processing part extracts this pilot signal from the mixed multi-carrier wave containing the level change which is input into the secondary coil by coupling with ground coils for ATS. Next, it calculates a curve to change the level of the pilot signal and this curve is transformed into a reverse curve. Finally, the mixed multi-carrier wave containing the level change is multiplied by this reverse curve and normalized. By FFT analysis in DSP, the spectrum of normalized signal is calculated. It is possible to calculate \( f_0 \) and \( Q \) of the ground coil for ATS precisely from the spectrum data led above.3
3. Construction of new maintenance system

The construction of the developed maintenance system, which can be mounted on a commercial train, is shown in Fig. 3. The main function unit is divided into the measurement part for ground coils for ATS, track circuits, and electronic train detectors for level crossing. The data measured from each part is stored in the memory of the data management. The stored data on-board is processed by the wayside analysis system. The function of each part is described below.

3.1 Measurement part for ground coils for ATS

As mentioned in section 2.3, the primary coil of the sensor transmits a multi-carrier wave and a pilot signal simultaneously by using the multiplex oscillator. When the on-board sensor couples with the ground coil for ATS, a voltage is induced on the secondary coil of the sensor by the resonance current of the ground coil. After the induced voltage on the secondary coil is digitized, it is normalized by the pilot signal. The normalized signal is submitted to FFT analysis by DSP. The result is transmitted to the data management part, and, after it is added with the distance information and line section information, it is stored in the memory. The wayside analysis system calculates $f_0$ and $Q$ of ground coils from the stored data on-board.

We verified the functional performance of the measurement part for ground coils in our high rotation testing machine as shown in Fig. 4. While the ground coil installed on the test board was rotating at high speed, we measured its $f_0$ and $Q$ by using this system. By changing the distance between the sensor and the ground coil, and changing the rotation speed, we checked the precision of the measurement against $f_0$ and $Q$ of the ground coil. The result is shown in Figs. 5 and 6. It is confirmed that this system can measure $f_0$ and $Q$ of the ground coil approximately without errors regardless of the distance between the sensor and the ground coil. Therefore, the measurement method of this system is not much influenced by the changes in the distance. On the other hand, as the rotation speed becomes faster, the measurement precision of $Q$ drops, in particular. But this system has precision of $\pm 0.1$ kHz for $f_0$ and $\pm 10\%$ for $Q$, even if the rotation speed is 120 km/h.

3.2 Measurement part for track circuits

In this maintenance system, a common sensor used for measuring ground coils measures track circuits. As shown in Fig. 7, the electric testing car has two sensors. One sensor is used for measuring ground coils, and the other sensor is used for measuring track circuits and electronic train detectors for level crossing. But, in order to downsize this system, a single sensor measures ground coils for ATS, track circuits and electronic train detectors for level crossing. So this system doesn’t require a large space when installed on an underfloor plate. The current of track circuits induced on the secondary coil of the sensor is sampled every 0.5 m, and the root mean square current value is calculated by DSP. The current frequencies of track circuits, measured by this system are 25 Hz, 30 Hz, 50 Hz, 60 Hz, 83 Hz, 100 Hz, and 120 Hz. This frequency band is used in divided frequency track circuits, divided-and-doubled frequency track circuits, and other JR tracks. The measured results of the current frequency and the root mean square current value of track circuits are transmitted to the data management part and stored in the memory.
Fig. 4 Outline of the laboratory test by the high rotation machine

Fig. 5 Measurement error of frequency in this system

Fig. 6 Measurement error of Q in this system
The measurement process of the part for electronic train detectors for level crossing is the same as that of the track circuit part mentioned above. It samples the current of electronic train detectors every 0.5 m by the common sensor used for measuring ground coils and track circuits. The kinds of electronic train detectors for level crossing measured by this system are as follows.

1) Closed track circuit type (oscillation stops when a train approaches): 8.5, 8.7, 8.91, 9.1, 9.34, 14, 20 kHz are used.

2) Open track circuit type (oscillation starts when a train approaches): 9.56, 9.79, 10.2, 10.26, 10.5, 30, 40 kHz are used.

This system can measure the root mean square current value, the current frequency, and the detecting distance of each electronic train detector for level crossing.

We describe the method of calculating the detecting distance of electronic train detectors for level crossing. As shown in Fig.8, in the case of open track circuit type, the peak point of current measured by the sensor mounted at the head of the train is coincident with the peak point of current measured by the sensor mounted at the end regardless of the train length. Therefore, the detecting distance of open track circuit type is the total moved distance of a train while each sensor mounted at the head and the end detects the current of electronic train detectors for level crossing.

On the other hand, as shown in Fig.8, in the case of the closed track circuit type, the detectable distance is found by subtracting the train length from the distances between the peak point of current measured by each sensor mounted at the head and at the end.

4. Results of field test

We conducted a field test of the newly developed maintenance system to confirm its performance. At first, for example, the measured result of the ground coil when the train ran at 30 km/h is shown in Fig.9 and, that when the train ran at 119 km/h is shown in Fig.10. These Figs. display the spectrum of induced voltage on the secondary coil and \( L_c \) and \( Q \) of the ground coil which were calculated from the spectrum data. Also, displayed is the 1st order derivative curve of the spectrum with respect to frequency. This 1st order derivative curve is used to confirm the reliability of the measured result. The spectrum curve, which is calculated from the induced voltage by coupling with the ground coil, should have only one peak. And because the 1st order derivative curve has 0 crossings.
only at the point that the slope of spectrum curve becomes 0, i.e., the peak point of spectrum curve, the 1st order derivative curve should have only one 0 crossing point. Thus, if the 1st order derivative curve has only one 0 crossing point, the reliability of the measured result is rated high. As shown in Figs. 9 and 10, at any train speed, this system can reliably measure $f_0$ and $Q$ of ground coils for ATS.

Next, the measured result of the track circuit is shown in Fig. 11. We have confirmed the precision of measured current and frequency of the track circuit. Fig. 11 shows that the current value increases as approaching from the receiving part to the transmitting part in the track circuit.

Finally, the measured result of the electronic train detectors for level crossing is shown in Fig. 12. As shown in Fig. 11, this system could measure the current value, current frequency, and detecting distance of electronic train detectors for level crossing precisely. We have also confirmed that this system can measure ground coils, track circuits, and electronic train detectors for level crossing by only a single sensor used in common.

5. Conclusions

We have developed a compact maintenance system for railway signalling equipment that can be mounted on a commercial train. This system shares a single sensor to measure ground coils for ATS, track circuits and electronic train detectors for level crossing. Moreover, it can measure signalling equipment precisely, even if the train runs at high speed. We consider that this maintenance system can save labor, measure the signalling equipment more frequently, and make technological innovations in maintenance. From now, we will perform more field tests to improve this system.

References