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Analysis and Design of Ground Speed and Position Detection System Based on Crossed Inductive Looped-cable

Abstract. *This paper introduces the structure and principle of ground speed and position detection system based on crossed inductive looped-cable, and analyzes the impedance matching of loops in details, then the calculated model is given. Considering the application environment, this article also analyzes the effect taken by the sleeper, and puts forward the method of improving system reliability. Finally, this system was tested by experiments taken on the maglev track. The result shows that it has a good performance.*

Streszczenie. *W artykule przedstawiono budowę systemu rozpoznania pozycji i prędkości obiektu względem ziemi. Działanie oparte zostało indukcyjności zbudowanych cewek (pętli kablowych). Dokonano analizy dopasowania impedancyjnego odpowiednich cewek. Opracowano model systemu. Jego działanie poddano weryfikacji eksperymentalnej w pojeździe typu maglev. (**Analiza i projektowanie systemu pomiaru prędkości względem ziemi i określania pozycji w oparciu o indukcyjność pętli kablowych**).*

Keywords: Maglev train, Speed and position detection, Crossed inductive loop-cable, Impedance matching.
Słowa kluczowe: pociąg Maglev, detekcja prędkości i pozycji, skrzyżowane pętle indykcyjne, dopasowanie impedancyjne.

Introduction

With the accelerating process of the urbanization, the scale and density of urban rail transportation increase quickly. As a new generation of transport, maglev vehicle, which uses electromagnetic force to achieve non-contact support and guidance, has many advantages, such as adaptability to the terrain, flexible with the route line selection, safety and environmental protection[1-4]. In the automatic control system of maglev train, speed and position detecting is a key technology, which must be designed by using a non-contact measurement method, as the maglev train doesn't have physical contact with the rails in the process of operation. Speed and position of train are measured on board in previous methods, and the communication system is added for the purpose of speed and position information acquisition in the control room on ground, but these methods have the defect of low reliability, both measurement system failure and communication fault can make the system does not work[5-6]. This paper introduces the structure and principle of ground speed and position detection system based on crossed inductive looped-cable firstly, and analyzes the impedance matching of loops in details, then the calculated model is given. Considering the application environment, the effect taken by the sleeper is also studied in this article, and the method of improving system reliability is put forward. In a word, the analysis lays a theoretical and experimental basis for the application of ground speed and position detection system based on crossed inductive looped-cable to maglev train.

System Structure Design and Principle Introduction

The structure of ground speed and position detection system based on the inductive loop-cable is shown in Fig. 1.This system makes use of assistant equipments fixed in train and rail respectively to realize non-contact measure, and is mainly composed of two parts: magnetic excitation on board and inductive signal processing on the track. The former, including transmitting coil, signal generator and power amplification circuit, is used to send the periodic oscillator signal while the inductive signal processing part is to change the inductive signal into speed and position signal, including crossed inductive loop-cable, impedance matcher, signal processing circuit and output device.

Firstly, magnetic excitation part sends the high frequency oscillator signal to the antenna fixed in the bottom of the vehicle, and there is regular magnetic field produced in neighborhood of the coil according to the law of electromagnetic induction, then the crossed inductive looped-cable with the strictly same shape below the coil on ground could detect the regular change of the alternating magnetic field and have the induced electromotive force. When the train runs, the amplitude of induced electromotive force varies regularly, and this change can be detected at the terminal of loop-cable. Then the location and speed signal can be obtained by sampling, and subdividing of electromotive force amplitude in the signal processing circuit, which is shown in Fig. 2.

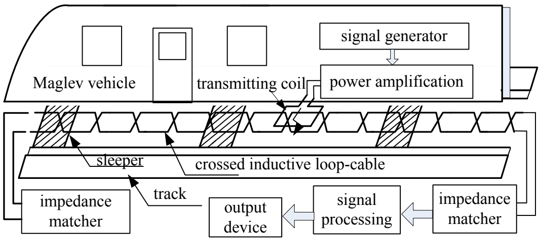

Fig.1. The sketch map of ground speed and position detection system based on crossed inductive looped-cable

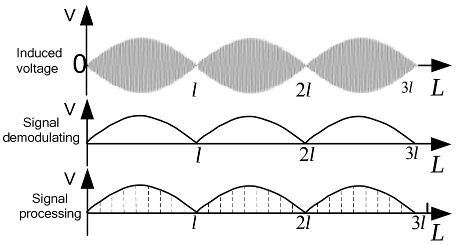

Fig. 2. Processing of received signal

Theoretical analysis and derivation of impedance matching in long-distance crossed loop-cable is given below to reduce the attenuation of the signal.

Realization of impedance matching

The crossed inductive looped-cable has the structure as Fig. 3, and the size of a crossed period is $l \times l$, which can be equivalent to a circuit model of RLC. As the frequency of emission current in the speed and position detection system based on crossed inductive looped-cable is several kHz even several hundred kHz, and is so high that the role of resistance and conductance can be approximately ignored, the crossed loop-cable can be equivalent to the lossless line. In the non-cross section, distributed capacitance and inductance is the uniform respectively, and so are the ones in cross section. L_1 (x), C_1 (x) and L_2 (x), C_2 (x), represent the distributed inductance and capacitance in cross and non-cross section respectively, where x is the location of the point in the transmission line.

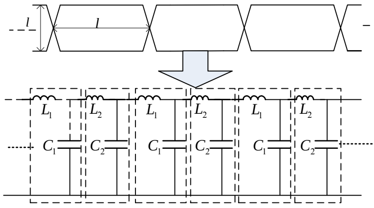

Fig.3. Equivalent circuit model of crossed inductive looped-cable

In a crossed period, the transmission line of cross and non-cross section can be respectively regarded as two two-port networks A and B, as shown in Fig. 4, then the cascade method can be used to obtain the whole characteristic impedance of a crossed period. Firstly the transmission parameters of networks A and B can be calculated, then transmission parameters of the whole crossed period network AB can be got by using the cascade property.

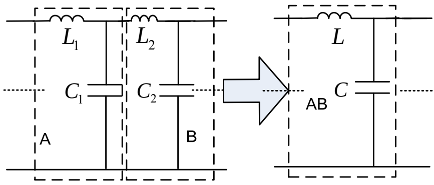

Fig.4. Cascade in a period

It is convenient to use transmission parameter in the analyzing the cascade of two-port networks, which can be calculated by using distributed capacitance and inductance, and the transmission parameters of two-port networks A and B are:

$$A^a=\begin{bmatrix}A_{11}^a & A_{12}^a\\ A_{21}^a & A_{22}^a\end{bmatrix}\quad A^b=\begin{bmatrix}A_{11}^b & A_{12}^b\\ A_{21}^b & A_{22}^b\end{bmatrix} \tag{1}$$

Then transmission parameter Aab can be got according to cascading equations:

$$A^{ab}=\begin{bmatrix}A_{11}^a & A_{12}^a\\ A_{21}^a & A_{22}^a\end{bmatrix}\begin{bmatrix}A_{11}^b & A_{12}^b\\ A_{21}^b & A_{22}^b\end{bmatrix} \tag{2}$$

Assumed that the characteristic impedance of loop-cable every crossed period is Z_c and the transmission coefficient is Γ ,then the output impedance at each crossed point is Z_c ,if the terminal impedance meets $Z_L = Z_c$, and the characteristic impedance of long-distance crossed loop-cable is the same with the one in a crossed period. The relation between transmission coefficient and characteristic impedance is:

$$Z_c=\sqrt{\frac{A_{12}A_{22}}{A_{11}A_{21}}} \tag{3}$$

When the load impedance meets $Z_L = Z_c$,impedance matching of loop-cable is completed. Then there is only traveling wave current and no standing wave, and the signal is absorbed at the terminal of loop-cable and would not be reflected. In this case, the amplitude of received signal is the same above every non-crossed section of loop-cable.

Analysis of sleeper effect

The analysis above is given in the ideal circumstance, however, the system of speed and position detecting is affected by the magnetic field and metal material nearby in the actual application. The transmitting coil is installed in the bottom of the maglev vehicle, and cross-induction loop is laid on the tracks, the large pieces of metal around includes sleeper, maglev train bogies, and the stator of the linear motor, and the effect of metal sleepers, which is under the loop-cable, is maximal, so the analysis of effect taken by the sleepers on the cross induction loop and the method of reducing this interference is given as below.

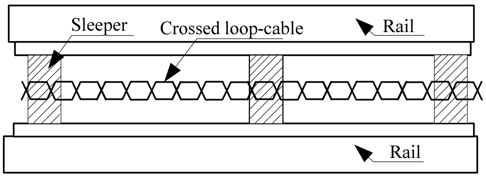

Fig.5. The sketch map of sleeper distribution

There are sleepers on the track every certain interval, whose material is steel, distributed as shown in Fig. 6 and Fig. 6. The electromagnetic parameters of sleeper are mainly conductivity and permeability, and both are large. When the transmitting coil passes by the sleeper, there is not only static magnetic effect, but also the appearance of the eddy current, which is shown in Fig. 6.

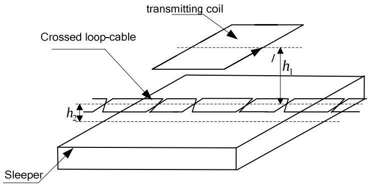

Fig.6. Sleeper lateral distribution

The magnet received by the coil above the sleeper is:

$$\begin{cases}\vec{B}_{\delta 1}(x,y,z)=\vec{B}(x,y,z-\delta)\\ \vec{B}_{\delta 2}(x,y,z)=\vec{B}(x,y,z+\delta)\end{cases},\quad \Omega : z>0 \tag{4}$$

$$\vec{B}_h(x,y,\delta)=\vec{B}_1(x,y,h+\delta)+\vec{B}_2(x,y,h-\delta) \tag{5}$$

Secondly, analysis of effect taken by eddy current is given. There is a current flow called eddy current inside the sleeper, as sleeper (large conductor) is located in a changing magnetic field, as shown in Fig. 9. Alternating magnetic field H_2 generated by eddy current in sleeper is opposite to the one H_1 generated by the detecting coil, so the magnetic field weakens. Eddy current equations are:

$$\nabla^2 H=\mu\gamma\frac{\partial H}{\partial t},\nabla^2 E=\mu\gamma\frac{\partial E}{\partial t},\nabla^2 J=\mu\gamma\frac{\partial J}{\partial t} \tag{6}$$

In order to simplify the calculation, assuming that $B=\nabla\times A$, $E=-\frac{\partial A}{\partial t}-\nabla\varphi$,and magnetic vector potential electric A and scalar potential φ are taken. The divergence of A is zero at the standard of lorentz force, so the equation can be got: $\nabla^2 A=-\mu J$, $\nabla^2\varphi=-\frac{\rho_v}{\varepsilon}$, According to current continuity theorem $\nabla\bullet\sigma(\frac{\partial A}{\partial t}+\nabla\varphi)=0$,the equation below can be calculated:

(7) $$\nabla^2 A-\mu\sigma(\frac{\partial A}{\partial t}+\nabla\varphi)=-\mu J_s$$

The conditions which magnetic vector potential electric A and scalar potential φ need to meet are:

(8) $$A_2=A_1, n_{12}\times(\frac{1}{\mu_2}\nabla\times A_2-\frac{1}{\mu_1}\nabla\times A_1)=K_s$$
$$\varphi_2=\varphi_1, n_{12}\bullet(\sigma_2\nabla\varphi_2-\sigma_1\nabla\varphi_1)=0$$

Assuming that the dimension of transmitting coil is $a\times b$, the eddy current magnetic field intensity at the position of detecting coil can be calculated according to variable separation approach. From the chart above, it can be regarded that the magnetic field at some point A in the crossed loop-cable above the sleeper, is generated by the transmitter coil, mirror coil and the eddy current together, which can be calculated as the following equation:

(9) $$B_A=\vec{B}_1(h+\delta)+\vec{B}_2(h-\delta)+\vec{B}_e(z)$$

The detection of coil equivalent inductance is simulated when the frequency varies, and the results is shown in the Fig. 7. From the simulation result, the inductance of detection coil decreases gradually with the increase of the excitation frequency. The existence of eddy currents reduces the excitation magnetic field strength, with the increase of f , the effect of eddy current becomes larger and larger, so the detection coil inductance gradually reduced. When the frequency f comes to $2.25kHz$, the inductance of measurement equals to the inductance of coil in the case of nonexistence of sleeper, and the effect of static magnetic and eddy current produced exactly cancel.

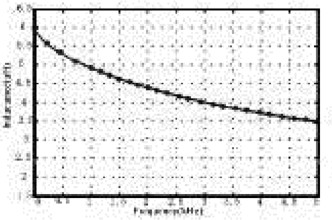

Fig.7. The result of simulation

Method of improving reliability

The purpose of signal processing is to detect the change of received signal amplitude, which is sensitive to the effect taken by train jitter, thus the accuracy of the speed and position decreases. In this case, the method of laying two crossed loop-cable is proposed below to improve the reliability of system, and the principle is shown in Fig.8.

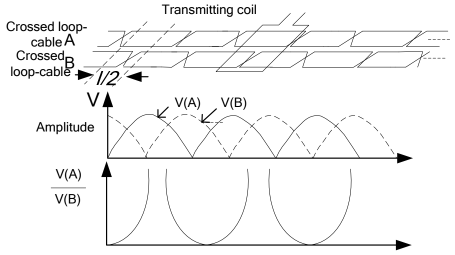

Fig.8. The method of improving reliability

As shown in Fig.8, another crossed loop-cable is laid besides the former one, and the distance of two loops in the laying direction is half of crossed period length.

Conclusions

This paper introduces the structure and principle of ground speed and position detection system based on crossed inductive looped-cable, and analyzes the impedance matching of loops in details, then the calculated model is given, which has been verified in application of long-distance crossed loop-cable. Considering the application environment, this article also analyzes the effect taken by the sleeper, and builds the mathematics model; the critical frequency is calculated according to image method and theory of static magnetic field, which is important to improve the accuracy of this system. In addition, this paper puts forward the method of improving system reliability to reduce the impact taken by train jitter.

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