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Wheel-rail Contact Force Monitoring Based on Wireless LC Oscillation Sensing

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Abstract

In this paper, to lay a foundation for monitoring wheel-rail contact forces, a non-contact inductor-capacitor (LC) tank composed of a rectangular printed circuit board (PCB) coil and a fixed capacitor is used to sense the variation of micro-properties in a C50 steel specimen caused by the uniaxial tensile force, based on magnetic inductive sensing. The test result shows the resonant frequency of the LC tank has a positive correlation with the loading force. It paves the way for the utilization of LC oscillators on wheel-rail contact force monitoring of high-speed railways.

Keywords: wheel-rail contact force, electrical micro-properties, LC oscillation, wireless sensing, resonant frequency, uniaxial loading testing, high frequency.

1 Introduction

The derailment coefficient related to wheel-rail contact forces determines a high-speed railway's running safety and stability [1]. The traditional approach to measuring the contact forces is achieved by strain gauges with a strict requirement for the wheels' treatment and a complicated processing and transmission circuit [2-3].

Electrical micro-properties (electrical conductivity σ, magnetic permeability μ) of high-speed railway wheels vary in response to wheel-rail interaction due to piezoresistive effect [4] and inverse magnetostrictive effect [5-6].

LC tank is the parallel connection of an inductor and a capacitor. It oscillates at a frequency related to its inductance and capacitance. It can be utilized for inductive force measurement [9] due to the magnetic inductive coupling effect.

This paper proposes a wireless LC tank based on magnetic inductive coupling to evaluate the relationship between resonant frequency and loading force on the C50 steel specimen.

2 Methods

Figure 1 shows the experiment set-up diagram implemented by the LDC1614 measurement system and the material testing machine. The LDC1614 is responsible for the inductance to the digital converter and is controlled by MSP430 which processes and operates the digital conversion results through I2C interfaces. A specimen is clamped by the wedge grips and loaded by the tensile machine. The load cell monitors the loading force, and its data is recorded. An LC tank (inductance 30μH on the air, fixed capacitance SMD 0603 330pF) connected to LDC1614 is in non-contact with the specimen with lift-off of 3mm. LDC1614 outputs pulse current to excite the LC tank, inducing a time-varying magnetic field around the inductor. When a specimen is brought into the vicinity of the LC tank, the magnetic field will induce eddy currents on the surface of the conductor (the function of permeability and conductivity). The eddy current generates its magnetic field, which opposes the original field generated by the inductor. The inductance of the LC tank varies with the eddy current. While the C50 steel sample is loading, its microscopic material permeability and conductivity change which affects the intensity of the induced eddy current, causing the variation of inductance and the corresponding resonant frequency of the LC tank.

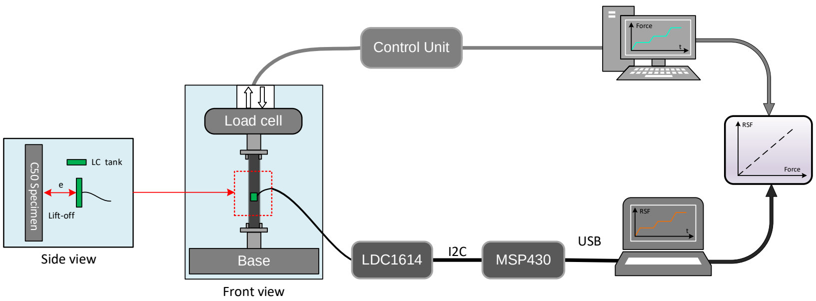

Figure 1: Experiment set-up diagram.

Figure 2 is an equivalent circuit model of an LC tank connecting to LDC1614 and wirelessly interacting with the C50 specimen. The specimen is treated as the series of an inductor L_m and a resistor R_m. Both are dependent on the specimen's permeability μ and conductivity σ. Variations of magnetic permeability and conductivity resulting from force loading influence the inductance of an LC tank. By using LDC1614, the final inductance combined with the function of permeability and conductivity can be monitored as the stress. Equation (1) describes the relationship between resonant frequency f_{res} and L_p and C_p. L_p is a function of lift-off e, L_m, R_m, $M_1(e)$, and force F.

$$f_{res} = \frac{1}{2\pi\sqrt{C_p \times L_p(M_1, L_m, R_m, e, F)}} \quad (1)$$

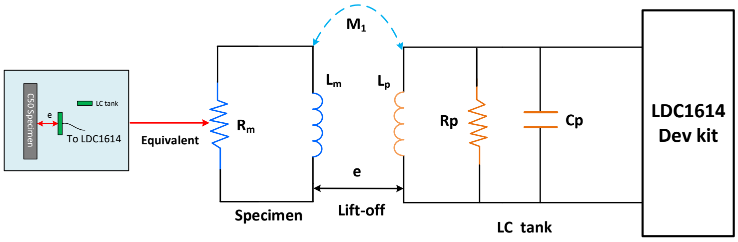

Figure 2: Equivalent circuit of LC tank and the specimen.

3 Results

Figure 3 shows as the loading force increase from 12kN to 28kN, the resonant frequency of the LC tank varies linearly from 1.644MHz to 1.658MHz. Due to the high-frequency eddy current effect, the change of magnetic permeability can be omitted and only the electrical conductivity is dominant because the permeability and the conductivity act differently for the inductance [6-7]. The former enhances the inductance because of magnetization while the latter weakens the inductance due to the eddy current effect [8]. The resonant frequency is positively correlative to the loading force with the sensitivity of 718.4Hz/kN and R^2 0.99413 in Figure 3, which can be explained by the increased conductivity with the tensile force at high frequencies [4].

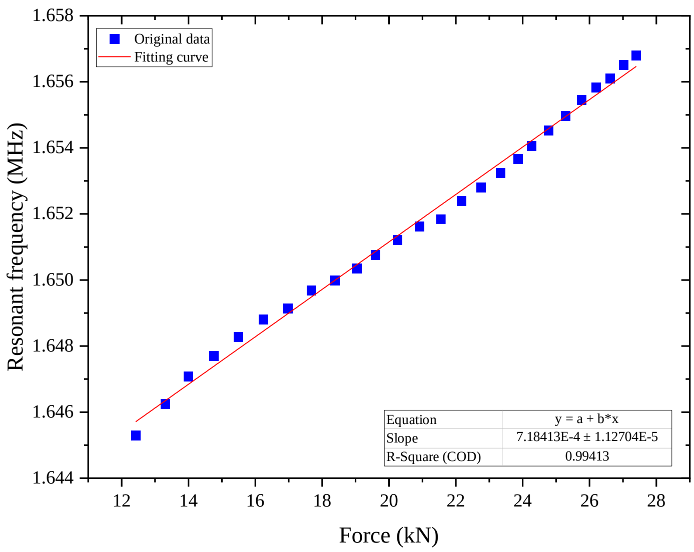

Figure 3: Relationship between loading force and resonant frequency.

4 Conclusions and Contributions

The LC tank with digital frequency output employing the miniatured and integrated LDC1614 system was used for the evaluation of the uniaxial tensile test of the C50 steel specimen. It can be concluded that the resonant frequency of the LC tank is approximately proportional to the loading force when the loading force is over 12kN on the specimen due to the change of the specimen's property (conductivity). This way is non-contact and provides new potential to replace strain gauges on wheel-rail contact force monitoring. Mathematical model establishment regarding force, magnetic permeability, electrical conductivity, and LC resonant frequency will be future work.

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