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Error Theory of Chord-based Measurement System regarding Track Geometry and Improvement by High Frequency Sampling

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Abstract: The chord-based measurement system has been used for a long time in the measurement of track irregularity, however, the error theory is seldom studied. As a typical case, the mid-chord offset system (MCO-system) is selected in this paper to study the error propagation of chord-based systems. The measurement model and restoration model are established to describe the measurement and restoration process of the MCO-system. To evaluate the accumulation of error, the Error Amplification Factor (EAF) is defined. The regularities of error accumulation are analyzed in the distance domain and the wavelength domain. Furthermore, an error propagation formula of different wavelengths is proposed. High frequency sampling is introduced to improve the performance of the MCO-system, where a least square model is established to handle the redundant measured data, and it can be theoretically proven that the influence of measuring errors can be reduced to zero if the sampling frequency approaches infinity. The error theory given in this paper is useful for designing devices based on the MCO-system and the error of different wavelengths can be accurately controlled. As an application, field measurement is carried out to verify the feasibility and correctness of the models by comparison with the restoration method using a digital inverse filter.

Keywords: Chord-based measurement; Track geometry irregularity; Error amplification factor; Error analysis; High frequency sampling

1 Introduction

Efficient and fast detection of track geometry irregularities is of crucial importance to high-speed railway maintenance. It is not only related to the vibration and noise of the environment, but also affects the traveling safety and comfort of the running vehicles [1-6]. A variety of measurement principles have been developed regarding track geometry irregularities [1, 7-26]. Among them, chord-based measurement systems and inertial-based measurement systems are the dominant techniques.

In the case of chord-based measurement system, a reference chord is formed between two points on the rails and the distance between this reference chord and a third position of the rail is measured [1-2, 8]. This reference chord, generally with a length of about 1m, moves along the rail propelled by a trolley or vehicle to achieve a continuous measurement of rail geometry. During the chord measurement process, the data is always changing along the rail, leading to an amplitude variation (ranging from 0~2) of amplitude transfer function [1-2, 8-10]. For the mid-chord offset system (MCO-system), the wavelengths where the amplitude of transfer function equals zero, namely the zero points, repeat periodically; it is therefore impossible for those wavelengths to be measured. The amplitude behavior can be enhanced if the chord is asymmetric, but in this case the phase is distorted [1-2, 8]. Instead, inertial-based measurement systems are used due to the existence of an inertial reference frame of accelerometers: the data does not change during the measurement [1-2, 12-17]. The displacement is then determined by double integration of the