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Review

Weigh-in-motion (WIM) sensor response model using pavement stress and deflection

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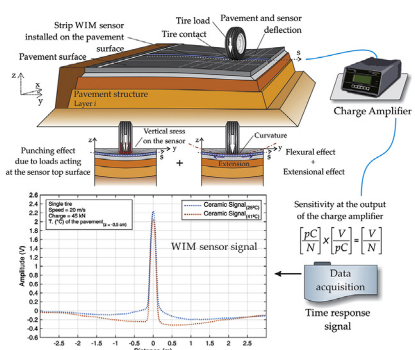
HIGHLIGHTS

- An electro mechanic (EM) model for WIM sensor considering pavement mechanic response.
- Laboratory and pavement mechanical approaches to obtain the EM model coefficients.
- Pavement elasticity and viscoelasticity proprieties to deliver the EM response.
- The EM model calculated show very close similarity with real WIM sensor response.

GRAPHICAL ABSTRACT



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ABSTRACT

This article aims at modeling the WIM sensor electrical behavior to provide a better understanding of the mechanical and electrical proprieties of piezoelectric sensors. The model is considered in the frequency domain, supposing any sinusoidal solicitation with constant frequency or any other type of solicitation. Tests, having real WIM sensors placed on the pavement of a test track at IFSTTAR/Nantes was used to verify the nature of the electro-mechanical (EM) behavior of the real sensors over punching, flexural and extension effects. Also, two different pavement numerical simulations deliver the mechanical response using linear elasticity and viscoelastic proprieties. The output of these two simulations are compared with two WIM signals obtained at same load and speed at two different temperature conditions.

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Contents

1. Introduction

Weigh-in-motion (WIM) technology is one of the main tools for pavement management. It can provide an accurate description of the traffic on road network recording class of vehicles (trucks, cars and motorcycles by the weight, number of axle, distance of axle and size), total gross weight and axle weight (sometimes, weight per wheel), speed, date and time of each event. WIM have potential to minimize the problems of overloading practice. Overload trucks pose serious threats to road transport operations, with increased risks for road users, deterioration of road safety, severe impacts on the durability of infrastructure (pavements and bridges), and fair competition between transport modes and operations [1]. In addition, traffic counting data are an important input of pavement management systems for anticipating the evolution of pavement damage and the need for maintenance.

WIM systems were introduced in the United States in the mid-1950s. First sensors used as scales were instrumented plates fixed in a frame mounted on the road, called bending plate scales. In the 80's, a new generation of WIM sensors was developed using piezoelectric technology to infer wheel forces by the electric charge produced. Since then, many developments and progress have taken place, while sensors and techniques have been introduced and implemented.

Early researches show that piezoelectric sensors could be one of the solutions for measuring axle loads and for weigh-in-motion applications [2]. The piezoelectric effect is a phenomenon whereby mechanical energy is converted to electrical energy (and vice versa) within certain insulating materials. WIM sensors are generally installed in the pavement surface course and made flush to the pavement surface. The sensors respond to changes of loads with time rather than loads themselves. The weight of axle loads is generally calculated by integrating the output with time and by multiplying the integral by the speed of the vehicle and a calibration factor [3].

Two major studies about WIM systems and sensors were undertaken in the 90's. The COST323 project aimed to gather information on WIM technologies, to develop and specify European techniques, to define data base protocol and publish recommendations concerning WIM applications [4]. In the same period, the WAVE project (Weigh-in-motion of Axles and Vehicles for Europe) objectives were to improve WIM accuracy and load measurements on pavements and bridges, to provide reliable information to management systems and to develop calibration methods suitable to all European climates [5].

Not all WIM sensors are made with piezoelectric materials but they work similarly, transforming the stresses induced by the vehicle in motion into an electrical response. Today, WIM strip sensors for pavement applications can be found based on quartz crystal, ceramics, polymers, or also electric strain gauges or optical fibers technologies. Some of their characteristics are presented below:

- The strip sensors with quartz technology are delivered as bars. The external part is an aluminum profile and the internal is filled with pastilles of quartz regularly spaced along the bar. They are mechanically independent one from each other, but are connected to the same conductive element to deliver the electric output. The internal shape is designed in such way that only vertical load stimulates the internal pastilles of quartz [6].
- The ceramic sensors are made of a powder ceramic compressed inside a metallic profile (some types are design as a tube with a circular compressed shape). A central core made of copper, connected to the output, collects the electric charge generated by the stress in ceramic element [7].
- The polymer strip sensor is composed by a polymeric film, made of PolyVinyliDene Fluoride (PVDF) spiral-wrapped inside of a copper flat tube. When load is over the sensor, compression acts on the tube which transmits to the polymer, an electrical charge is then transmitted to output [8].
- The optical sensor is designed with an optic fiber merged into a dense foam. The optical principles of measurement can be either based on polarimetry interpretation or in the Michelson interferometer. The components of the interferometer assess the fringe number and fringe period to approximate the load applied over the sensor [9]. In the polarimetric sensor, the light from a laser diode is polarized by a polarizing beam splitter and launched into a high birefringence transmission fiber, in such way, that only one polarization mode is excited [10]. An optical-electronic interface detects the changes in the optical signal and transforms them into electric signals for traffic data processing.
- The strain gauge strip sensors use strain gauges inside of a metallic profile. The WIM system correlates the strain measurement with the corresponding axle load value [11].

There are other WIM sensor technologies which has different response mechanism. For those cases, the electro-mechanical model does not apply.

In Brazil, the DNIT has started a national weigh-in-motion project in 2007 to evaluate WIM applications to Brazilian conditions of pavement and traffic. Two type of tests were performed, one concerning WIM accuracy and performance and a second about load damage on pavement structure. A test site was built near the city of Araranguá (Santa Catarina state, Brazil, 28°58′40.28″S, 49°32′4.84″W), near to the DNIT weigh station. There are four groups of sixteen WIM sensors (piezoelectric ceramics, polymer,