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FUNCTIONAL ANALYSIS OF A NEW CONCEPT OF WIM SENSOR BY USING FAILURE MODE AND EFFECTS ANALYSIS (F.M.E.A.)

BY

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Abstract. The overloading vehicle become an important problem for Europe Union, protecting the environment and increase the traffic safety. WIM or weigh-in-motion systems can monitor the traffic, determine the volume and type of traffic and detect the overload vehicles which are illegal. This paper discusses about applying the Failure Mode and Effect Analysis method for developing a new concept of WIM sensor, designed in PhD thesis from "Gheorghe Asachi" Technical University of Iaşi. FMEA method or also called potential failure modes and effects analysis is a step-by-step approach for determine and identifying all possible failures in a new design, or manufacture process. This new concept of sensor can be used for urban traffic in order to reduce the cars pollution in the cities by providing real-time data traffic, monitoring vehicles and detecting the overloaded trucks. The FMEA method was applied for identification of functional failure risks and preventing failures from an early stage of concept.

Keywords: WIM sensors; FMEA; Failure prevent; Safety; Pollution monitoring.

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1. Introduction

Failure Mode and Effect Analysis (FMEA) identifies the potential failure modes in a system by using cause and effects analysis. FMEA is a review, make it in the concept phase of the prototype, of future possible failure modes. One of the advantages of FMEA is that this is an action before-the-event and not an action after-the-fact", also the improvement by using FMEA method is the timeliness (Sematech Inc., 1992). The most important thing is that the FMEA needs to be done before starting the manufacturing process or to be included into production process. In order to be sure that the final product will satisfy the needs and expectations of the clients, through FMEA, the design characteristics are analysed in accordance with the production process. In case of any failure problem that may appear, it can be taken measures to reduce the occurrence of this kind of failure. The FMEA identifies the associated causes and provides an organized and critical analysis of the modes of failure that may occur. The FMEA relies on the probability of occurring and identification in combination with severity criteria to develop a number of risk priorities for the classification of critical actions. FMEA has been important for aerospace and automobile industries. The automotive industry uses this method more than other industries and although there are a lot of types of FMEAs the most know factor remains: to avoid the problems before they appear (Daimler-Chrysler Co. *et al.*, 2001).

2. Weigh-In-Motion (WIM) Sensors

The number by vehicles increases year by year and new traffic monitoring sensors must deal to a high volume of traffic data. Actual types of sensors can be used for the fallowing functions: determine the speed of the cars, weight of the vehicles, distance between axes, plate number recognition, determine the presence of a vehicle etc. The WIM sensors can weight the vehicles in motion without disturbing the traffic, can determine the vehicle's dimensions and can provide real time traffic data information (Barsanescu *et al.*, 2009). The WIM sensors can be intrusive or non-intrusive – can be embedded into road or can be mounted on bridges or wardrobes mounted next to the road (Agape *et al.*, 2019).

For a single location there are used several types of sensors for determining the vehicles parameters (Dontu *et al.*, 2020a). The sensors play an active role on road sections or smart bridges where they are installed (automatic activation of warning light signals, or for speed limitation, diversion or stop-resume of traffic, etc).

In USA there are two types of the most frequently used WIM sensors: wide sensors - where the tire footprint is in full contact with the active part of the sensor (such as bending plate sensors and load cell sensors) and narrow sensors - where the tire footprint is in partial contact with the active part of the sensor (such as strip sensors with quartz piezo, polymer piezo and strain gauge strip sensors). The difference in life cycle costs, over long periods of data collection, between bending plate and load cell compared with piezo sensors, decreases in time but the output data quality remain high, if the calibration is making on the time (U.S. Department of Transportation, 2018).

The main WIM sensors are:

- *Bending plate WIM sensor* – consist on a plate which has glued strain gauges on the underside of the plate for measuring the loading of vehicles passing on the sensor;
- *Load cell WIM sensor* - consists on two weighting platforms placed adjacent to each other where the force applied to the scale is measured with hydraulic or mechanical transducers (depending on the constructive solution). For installing the load cell WIM sensors, it is needed a concrete vault. The load transmitted to the platform is converted into an electrical signal which is proportional to the applied force;
- *Polymer Piezo WIM sensor* - consists on a copper strand, covered with a piezoelectric polymer material, which is also covered with a brass sheet. When the tire pressures on the piezoelectric material the piezo sensors detect a change in voltage so the output signal will be proportional with the applied force (Fig. 1);
- *Quartz Piezo WIM sensor* – Quartz crystal technology it's used to measure the vertical forces applied by the vehicle's wheels. The quartz crystals produce an electrical charge and the sensor is very precise;
- *Strain Gauge Strip WIM Sensor* – consists on a strain gauge load cell technology, so when the vehicle passes on the sensor the vertical load applied to the sensor measures it.

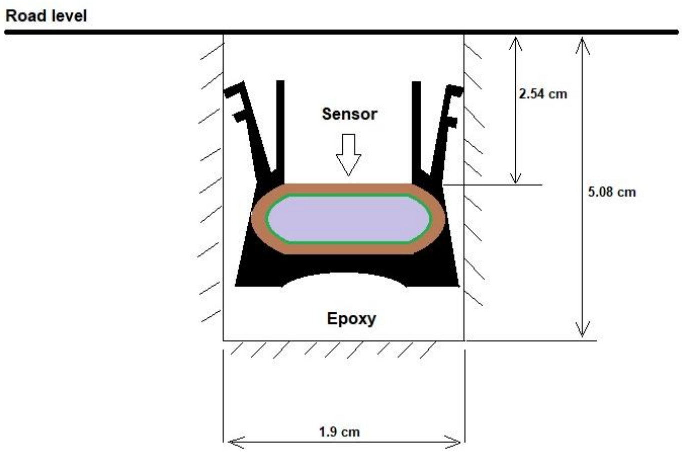

Fig. 1 – Polymer Piezo WIM sensor installation.

3. Application of the FMEA Method for a New Concept of WIM Sensor

A.I. Dontu *et al*. developed a new concept of WIM sensor designed for urban traffic monitoring; the objective of this kind of sensor is to weigh-in-motion vehicles, determining the type of the cars which pass the sensor, reduce the pollution in cities by giving real-time data traffic and that conduct to avoid the traffic jams. The sensor can be easily installed/uninstalled and also can be moved from one place to another one. The sensor has the dimensions of a speed bumper. The top plate of the WIM sensor works the same as a bending plate sensor. On the inferior part of the top plate will have some strain gauges glued. When the car passes the sensor the change in resistance of the strain gauges will be proportional with the force applied. Other sensors can be used for: determining the speed of vehicles and the number of vehicle's axles it can be used two piezocables; for increase the accuracy it can be used thermocouple and accelerometer. The WIM sensor developed is described in Fig. 2 (Dontu *et al.*, 2020b).

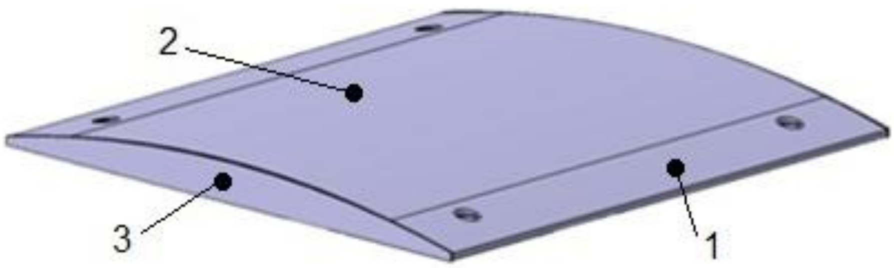

Fig. 2 – Computer-aided Design (CAD) of the sensor, where:
1 – bottom plate; 2 – top plate; 3 – lateral cover.

A few different types of FMEA analyses exist, such as: functional, design or process. For this type of sensor, it was applied functional FMEA analyses for determining and preventing the potential functional failure of the system (Pang *et al.*, 2019). For making the Failure Mode and Effects Analysis we consider our system composed of speed bump (case) which includes temperature sensor, accelerometer, force sensor and piezocables; and a steel box which includes data acquisition board, radar, video camera, computer and software, and the analysis was based on functionality of the entire system.

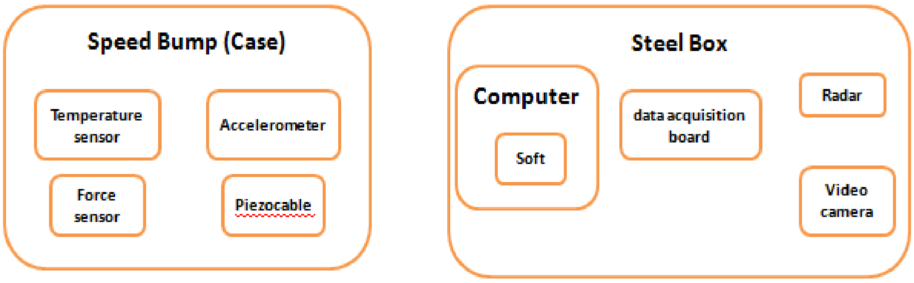

Fig. 3 – WIM system components.

The name of the software which has been used for making the Failure Mode & Effects Analysis is APIS IQ-RM and is a free-trial software. In Fig. 4a are presented the components of speed bump (case), by using APIS, and in Fig. 4b was developed the functionality tree structure for speed bump (case).

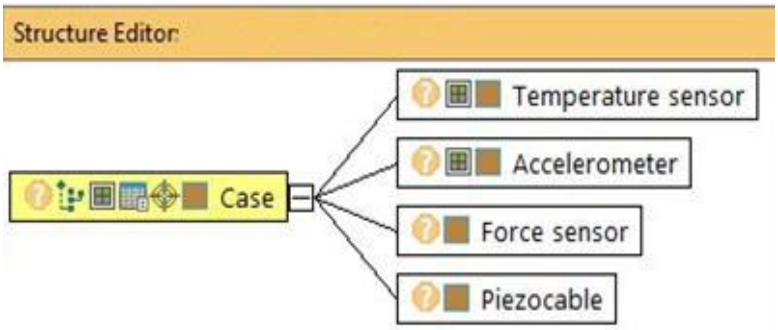

Fig. 4a – The sensors from inside the case (speed bump).

In picture are presented the sensors which will be inside the case (speed bump) and in the picture bellow are presented the functionality of the case (on the green): the case needs to be easily to install/uninstall; protect sensors by mechanical vibrations; protect sensors by temperature variations, need to include all the sensors and meet legal requirements. Also, there are presented failures that could appear on each point (on the red) - for each function that the case needs to have there are presented the failures. On the blue writing there are presented the product characteristics that the case (speed bump) needs to have: case material and case dimensions. For each product characteristics there could be some failures like: case material - wrong shielding material chosen (as the shielding can't be doing on the material we choose) or wrong material chosen (as the material doesn't have the mechanical resistance coefficient to satisfy or the material is too much elastic and this could affect the measurements).

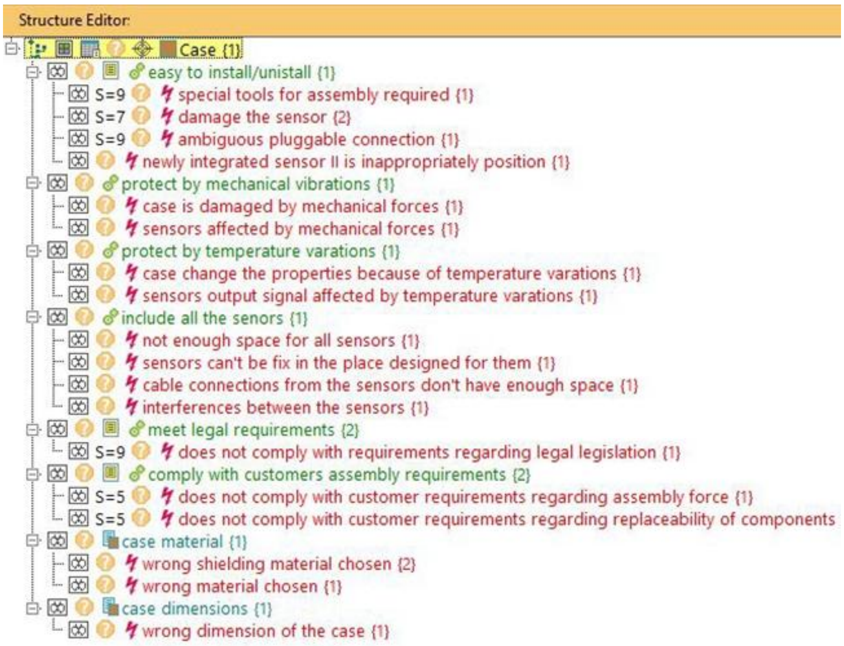

Fig. 4b – The functionality tree structure for speed bump.

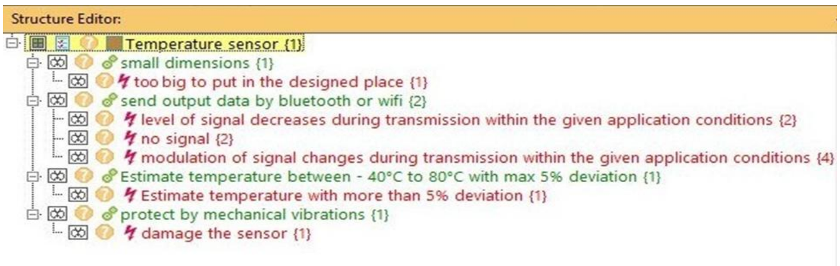

Fig. 5 – The functionality tree structure for temperature sensor.

In the picture is presented the functionality tree of the temperature sensor and the failures that could appear: need to have small dimensions (failure: too big to fix in the designed place), need to send the output data (measurement values) by Bluetooth or Wi-Fi to the processing board (failures: level of signal decreases during transmission within the given application conditions, no signal, modulation of signal changes during transmission within the given application conditions), the sensor need to estimate temperature between -40°C to +80°C with maximum 5% deviation (failure: the deviation could be more than 5% and this will could affect the measurements), the sensor need to be protected by mechanical vibrations (failure: the sensor can be damaged by the vibration caused by vehicles which are crossing the sensor).

The functionality tree of the accelerometer and the failures that could appear: need to have small dimensions (failure: too big to fix in the designed place), need to send the output data (measurement values) by Bluetooth or Wi-Fi to the processing board (failures: level of signal decreases during transmission within the given application conditions, no signal, modulation of signal changes during transmission within the given application conditions), the sensor need to measuring the dynamic acceleration produced as a result of shocks, motion, impact or vibrations with maximum 10% deviation (failure: the deviation could be more than 10% and this will could affect the measurements by introducing higher vibrations into the system), the sensor need to be protected by mechanical vibrations (failure: the sensor can be damaged by the vibration caused by vehicles which are crossing the sensor).

The functionality tree of the force sensor and the failures that could appear: need to have small dimensions (failure: too big to fix in the designed place), need to send the output data (measurement values) by Bluetooth or Wi-Fi to the processing board (failures: level of signal decreases during transmission within the given application conditions, no signal, modulation of signal changes during transmission within the given application conditions), the sensor need to measuring the force produced with maximum 5% deviation (failure: the deviation could be more than 5% and this will could affect the measurements), the sensor need to be protected by mechanical vibrations (failure: the sensor can be damaged by the vibration caused by vehicles which are crossing the sensor), the sensor need to be well fixed (failure: if the electronic connection or the sensor is not well fixed the indicating values could be wrong).

The functionality tree of the piezocable and the failures that could appear: need to have small dimensions (failure: too big to fix in the designed place), the sensor need to identify the presence of the vehicle (failure: the sensor could not determine the number of the car axles and also could not determine the speed of the vehicle), the sensor need to be protected by mechanical vibrations (failure: the sensor can be damaged by the vibration caused by vehicles which are crossing the sensor).

4. Conclusions

This analysis can identify the potential failure modes in a system by using cause and effects analysis. FMEA is a review, the concept phase of the prototype, of future possible failure modes. This new concept of WIM sensor can be used for urban traffic to reduce the cars pollution in the cities by providing real-time data traffic, monitoring the vehicles and detecting the overloaded trucks. The FMEA method was applied to identify the functional failure risks and prevent the failures from an early stage of concept. With the help of the FMEA method it can be established new requirements for the WIM sensor such us: each sensor need to satisfy some requirements for good work of the WIM sensor, the case of the WIM sensor needs to protect the inside sensors by mechanical vibrations, the case needs to be easily installed/uninstalled in case of any emergency error of a sensor that can conduct to wrong measurements results.

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ANALIZA FUNCȚIONALĂ A UNUI NOU CONCEPT DE SENZOR DE CÂNTĂRIRE ÎN MIȘCARE UTILIZÂND ANALIZA MODULUI DE DEFECTARE ȘI EFECTELE ACESTORA (A.D.M.E.)

(Rezumat)

Scopul principal al acestei lucrări a fost de a analiza funcționalitatea componentelor senzorului nou dezvoltat, utilizând metoda A.D.M.E., precum și identificarea posibilelor erori ce pot impiedica buna funcționare a dispozitivului.