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METHODOLOGY OF DIAGNOSTIC IDENTIFICATION FOR THE TRAIN

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Abstract

This article shows the results obtained during the implementation of a portable diagnosis system to the maintenance routines of the passenger vehicles and permanent track of the Metro de Medellín Company, which made possible the evaluation of aspects as: safety, comfort and technical condition of the track-vehicle interphase. The reports given in this evaluation allowed the identification and the arrangement of the track sections according to its technical condition, relating thus the track condition parameters and the vehicle to the estimators associated to the passenger vehicles dynamics.

Keywords: *diagnostic system, technical condition, safety, comfort, dynamic state*.

1. Introduction

The portable diagnosis system - SPD is an unique development for the railway systems, which besides evaluating safety, comfort and monitoring the condition of the geometric parameters of the track - vehicle interface, also allows to carry out the multidimensional monitoring of the condition and to determine the generalized failures of the passenger vehicles of the Metro de Medellín. The previous is possible due to the algorithm named Condition Inference Agent – CIA

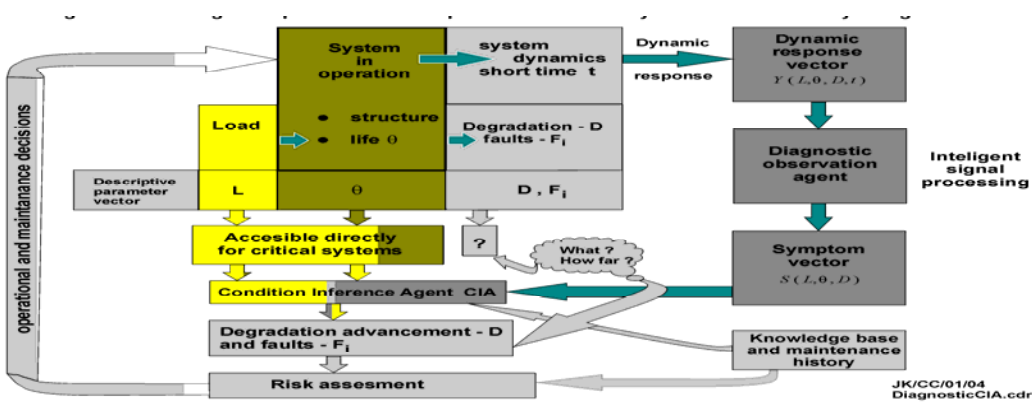

Fig. 1. Flow of information and processing in a system of operation and a subsystem of condition of intelligent monitoring [5]

which was incorporated in the design of the SPD (Fig.1). This algorithm was designed in European diagnosis institutes for the technical critical systems of operation, in order to increase the maintenance indicators of reliability and availability. To develop this diagnosis tool, there were used different methodologies that group several modern and effective methods in the diagnosis tasks, which go from the selection of measurement points, through the method of evaluation of the UIC 518 norm until the utilization of an optimized forecast method. The aim of this article is to shows the different methodologies previously pointed out [1,2,3,4].

2. Design of the portable diagnosis system _ SPD

The current operation scheme of the SPD doesn't apart from the initial design approach; the system is composed by eight modules: sensors, signal processing, monitoring of the condition, condition test, incipient failures detection in the wheel-rail interface, decisions support, forecast and presentation. The modules were developed using different methodologies related to the evaluation of current and future technical condition of the devices; these modules required the elaboration of the following diagnosis tasks:

- selection of the SPD measurement points;
- evaluation of the safety and comfort aspects according to the UIC 518 code;
- principal components of the SPD Observation Vector;
- multidimensional monitoring of the condition;
- forecast method to determine the next value parameter of diagnosis in the exploitation.

The selection of measurement points is used during the design of the SPD, due to the quantity of sensors installed in the passenger vehicles during the implementation of the UIC 518 norm and the required time for the configuration of the sensors, record and data analysis. The following mathematical functions were used to obtain the minimum of data acquisition channels that the diagnosis portable system uses to evaluate the safety and comfort of the passenger vehicle:

- coherence between the diagnosis signals:

$$\gamma_{xy}^{2}\ (f) = \frac{\left|G_{xy}(f)\right|^{2}}{G_{xx}(f)G_{yy}(f)} \leq 1$$

- coherence function area:

$$A\gamma_{xy}^{2} = \int_{0}^{F} \gamma_{xy}^{2}(f)\ dF$$

- affinity or similarity of the information of the diagnosis points:

$$In_{xy}(\Theta_i) = \sum_{x=1}^{l} \lg \frac{1}{1 - \gamma_{xy}^{2}(f_x, \Delta f_x, \Theta_i)}$$

These previous expressions ruled out channels in the vehicle box and in the bogies axle end, under the criteria of maximum coherence $\gamma^2(f)$ in the power spectrum $G_{xx}(f)$ of the obtained signal, which belong to the typical frequencies of the track – vehicle interface, the maximum area under the coherence function curve and the maximum similarity of information in the slow time Θ (see Fig. 2). The number of transducers of the diagnosis portable system in the test vehicle diminished in a large quantity due to this study. The SPD has four low frequency accelerometers and two force sensors to evaluate the safety, the comfort and the technical state of the trains.

With the purpose to evaluate safety and comfort in the passenger vehicles according to the UIC 518 norm, algorithms were developed to carry out the international standard procedures, which include the following:

- conditions of implementation: test speed, cant insufficiency, test zones and test vehicle conditions;
- signals record: right and left lateral force of axle-wheel set, vertical acceleration in the gearbox, lateral acceleration in the chassis of the bogie, lateral and vertical acceleration in the passengers' box ;
- dynamic quantities of evaluation: resultant lateral force, lateral acceleration in chassis of the bogie, safety, quasi-static lateral force, lateral and vertical acceleration in passenger's box for the comfort, r.m.s. lateral and vertical acceleration in passengers box for the comfort, quasi-static lateral acceleration, instability criterion;

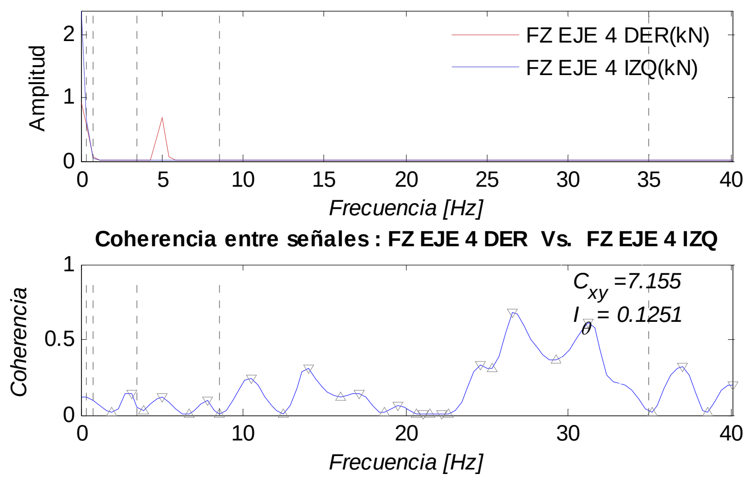

Figure 2: Analysis of affinity of diagnosis information

- selection of the tests track: tangent track zone, with small and large radius curve;
- statistical processing: per section and per test zone.

The principal components of the observation matrix Q (SQM - Symptom Observation Matrix) are calculated from the data obtained in the implementation of the UIC 518 norm. The following matrixes were developed in order to reproduce the evolution of the technical state of a curved or tangent section and its influence in the wheel - rail interaction, the relation between the dynamic quantities evaluated in the tangent and curved sections with the geometric parameters that are monitored in the maintenance routines of the Metro and the function that describes the life average of the passenger vehicles. The following are the arrangements for the previous purpose:

- the $S_i(\Theta)$ vector of the Q observation matrix, is composed by the value of the UIC 518 norm estimators, from which was evaluated the safety and comfort of the Metro system and the geometric parameters of the track (cant, gauge, horizontal and vertical alignment and synthetic coefficient); on the other hand the $\{S\} = \{S_1,.....S_S\}$ observation vector represents the train condition in the different curved or tangent sections of the test zone in the permanent track;
- the components of the $S_i(\Theta)$ vector of the Q observation matrix are: the maximum values estimated of the dynamics quantities which evaluated the safety and comfort in the different sections -tangent or curved- , the geometric parameters of the wheel (differences of diameter between axles, the same

vehicle and between adjacent vehicles, flange thickness, flange height, point 70 and diameters of the axles) and the indicators of the internal and external noise that is generated by the trains. The $\{S\} = \{S_1, \ldots\ldots S_S\}$ observation vector represents the state of the different test vehicles in different instants of life cycle.

Passive Experiment - BEDIND is the algorithm used to calculate the principal components of the observation matrix, its function is to classify the information that is linearly independent in an orthogonal space of failures[5]. For this purpose the algorithm uses the mathematical theory of eigenvalues and the following functions:

- variability of the experiment:

$$ZZE(S_t) = \sum_{i=1}^{s} \lambda_i \text{ , } where,\ \lambda_i \ are\ the\ eigenvalues\ of\ the\ observation\ matrix$$

- redundancy or over dimension of the experiment:

$$R(S_t) = \lg_2 \sqrt{\frac{\prod_{i=1}^{s} \sigma_{si}^2}{\prod_{i=1}^{s} \lambda_i^2}} \ Bit, \quad where\ \sigma_{si}\ is\ the\ s\tan dard\ deviation\ of\ the\ symptoms$$

The procedure finally obtains the components of the vector of observation which fulfill with the following criteria:

$$\underset{t=1,\ldots\ldots,s}{\vee ZZE(S_t) = \max} \quad \text{and} \quad \underset{t=1,\ldots\ldots,s}{\vee R(S_t) = \min}$$

The algorithm of multidimensional monitoring named CIA (Condition Inference Agent) has as task trace and monitor the widespread failures of the railway system, for this purpose the CIA uses a mathematical tool named SVD (Singular Value Decomposition), which helps to the obtaining of the magnitude, direction and sense of the failures which appear during the development of the technical system. In addition, the Condition Inference Agent gives compound measurements which are associated with the dispelled energy on the outside and inside of the technical system, as the Frobenius norm and the determinant of economic decomposition. The Fig. 3 shows the evolution of the widespread failure of the test units due to the technical state of the test zone.

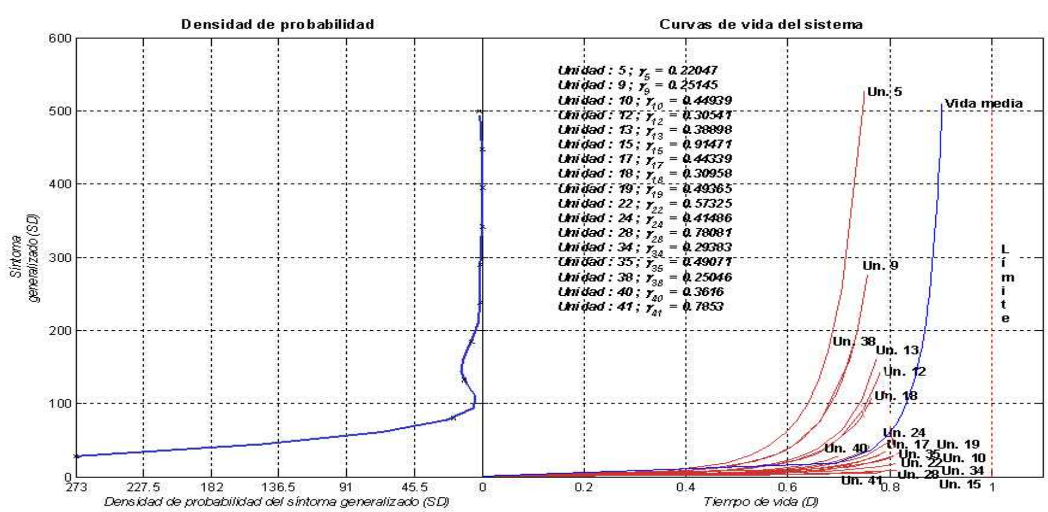

Fig. 3. Evolution of the widespread failure in the test units

The condition test unit gives the necessary information to carry out a technical diagnosis, as the geometric parameters of the track - vehicle interface and the dynamical behaviour data of the railway vehicle during its travel through the tangent and curved sections. The following module "incipient failures detection" was developed based on the studies made by the manufacturer of the passenger vehicle and the experts who have verified the passenger vehicle dynamics. They determined the typical frequencies of the transport system which were corroborated with the signals acquired during the implementation of the UIC 518 norm and analyzed in the domain of amplitude, time and frequency. The "Decisions Support" is the last but one SPD unit which is created by means of an inference motor which integrates the variables records related with the wear of the track. "Forecast" is the last SPD module which is supported in the "Vehicle" algorithm. This algorithm defines a set of diagnosis parameters and the best method of forecast in order to establish the next diagnosis term, the reliable range and the forecast error. The results obtained from this methodology are optimized under the criteria of the minimal coefficient of error relative difference and the minimal error radius of forecast.

3. SPD - portable diagnosis system

The principal function of the SPD modules is to evaluate the safety and comfort of the railway vehicles and the technical state of the track - vehicle interface. The sensors module is the hardware of the SPD system, which means acquisition system with its respective transducers. The units of processing sign and monitoring of the condition are constituted by the configuration of the transducers, the record, the data analysis and the reports according to the UIC 518 norm (Fig.4).

Fig. 4. Portable Diagnosis System Modules – SPD

The three previous modules allow the implementation of the international norm which means the configuration of the conditions of implementation of the test zones, the measurement of the quantities related to the dynamical behavior of the vehicles, the conditions for the automatic and statistical processing of the data, the evaluation of the quantities measured and the limit values.

The maintenance staff of the Metro has access to the module of "Evaluation of the condition" by means of a virtual map of the railway route, where can be selected the tangent or curved section as object of study. This SPD unit contains the historical information and the current state of the variables related to the track - vehicle interface. The Failures Detection Module contains the tools to monitor the frequencies related to the roll of the railway vehicle, the force level in the different track sections and the visualization of the switches effect on the set of axle - wheel railway.

The Decisions Support Module give the necessary recommendations to the staff of the Metro de Medellín about the maintenance activity that must be done in the different tangent and curved sections. These recommendations were designed based on a correlation study realized between the dynamical quantities measured of the UIC 518 norm and the geometric variables of the track - vehicle interface.

Nowadays the Portable Diagnosis System is being used by the maintenance staff of the Metro de Medellín. The SPD is a tool to evaluate the track - vehicle interface based on the condition, which will allow the improvement of the current practices of -corrective, preventive and predictive- maintenance. The diagnosis system is a support that helps in the development of the research project "Dynamical and geometric modeling of the track - vehicle interface ", in which are working the experts of the Metro de Medellín and the research group of the EAFIT University with COLCIENCIAS's funding. Finally, the incorporation of the SPD in the evaluation of the freight railway vehicles that nowadays pass along through the different Colombian routes is being considered (Fig.5).

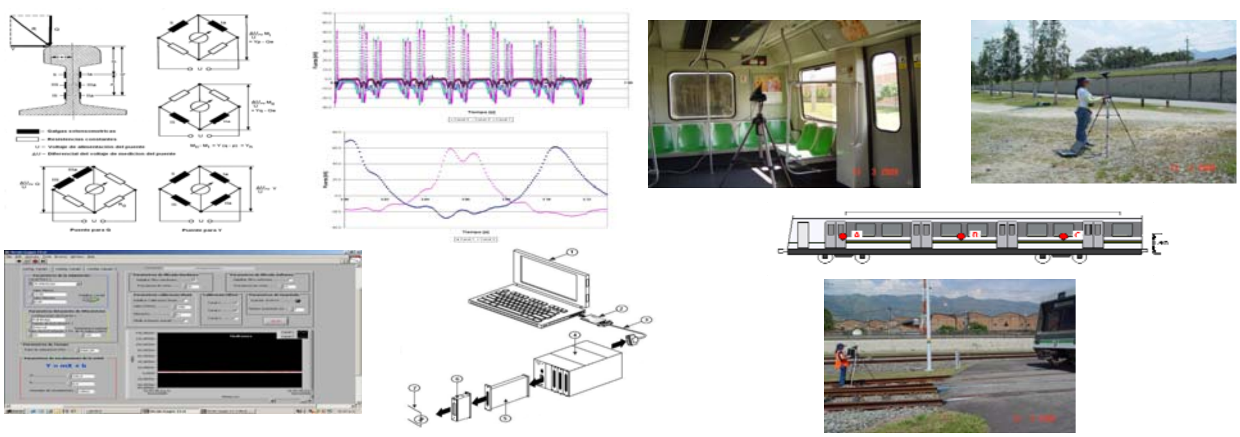

Fig. 5. a). Measurement with the SBB Swiss method. b). Measurement of noise in passenger vehicle

4. Conclusions

The goal of implementation of the UIC 518 international norm in the passenger vehicles of the Metro de Medellín was reached and as result the transport system fulfill with the requirements of safety and comfort stipulated by the norm.

The SPD gives to the Metro de Medellín a tool to evaluate the track - vehicle interface according to its condition, which will allow re-design the current maintenance routines with the purpose to reduce the maintenance costs in the company.

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