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Diagnostic Process of the Pantograph Current-Collector through an Acoustic Method

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Abstract: - In a railway system, trains get electricity through a structure mainly composed by *contact wires* and *pantographs*. The electricity runs through contact wire, a fixed wire suspended above railway tracks. Trains make contact with the wire and get the electricity that runs along the contact wire by means of a pantograph. In a railway system, a pantograph is a device fixed on the top of a train that reaches upwards towards the contact wire suspended above the train and creates the necessary contact between train and wire carrying electricity. The end part of the pantograph that touches the contact wire is known as *contact strip line.*
But if the surface of a contact strip line is not smooth, contact between pantograph and suspended contact wire you get vibrations, generally a frequency of thousands of Hz with constant time damping of few hundred seconds**.** These vibrations give rise to acoustic signals that can be picked up by microphones mounted along the track. The acoustic signal is filtered to a range of thousands of hertz using a specific data signal process. At this point a special device is used to analyse the signal and determine the roughness of the contact strip line that caused the vibrations.
Different experiments have been carried out to understand the specific parameters of the acoustic signal, the results tell us how rough a contact strip line actually is. The application of this method, to detect any defects in the pantograph, like undesired contact strip line roughness, is original.

Key-Words: pantograph-contact wire, contact strip line, dsp, wavelet transform

1 Introduction

A diagnosis of a complex system can be made by monitoring the conditions of all the basic components involved. A important diagnostic method can be obtained by following the response of a specific key element. In this case, the analysis only considers the acoustic element; as the rest of the system is either inefficient, or unable to provide the necessary information to perform the diagnostic process.
The subsystem “pantograph-contact wire” in the electric traction should be considered as a complex articulated system. [1] [2] [3] [4] Usually, a pantograph connects to the contact wire through a contact strip that is supported by a lightweight transverse frame with "horns" at each end (often you apply a layer of grease). Any contact wire and pantograph make up a dynamic subsystem that is subject to wear and deformation. If this subsystem doesn’t work properly it compromises pick up power and damages the material that supports the contact wire and/or the contact wire itself. [5] [6] [7] [8] [9] Any damage to this essential subsystem, in a larger railway structure, can be the reason for railway traffic or could even endanger passengers.[15] Due to contact wire oscillation and train high speed, the pantograph could separate from the contact wire for brief time interval. This fact generates electric arcs that not only make the wire wear out quicker, but also wear out the contact strip line surface. Practical maintenance must be guaranteed to prevent dangerous situations, therefore it is important to find an efficient method to monitor the state of pantographs transiting on train convoys.
The conditions of a system can be studied and analysed by comparing them with the response of a system that works well.
To carry out this comparison, you make a model that acts as reference of a system that works well or a standard system. This is done by identifying a set of parameters associated to the optimal system that stands for its behaviour and properties. Statistical techniques or methods based on know-how, allow you to compare the parameters of the models being tested and the reference models that represent different possible interesting effective situations.

2 Diagnostic Alternatives

The first thing to do to monitor a system, is assess efficiency and cost effectiveness of the diagnostic method being considered. In this case, an acoustic method is better than a visual one – whether it is visible or infrared, or whether they are methods

requiring a study of contact strip surfaces (using a profile metre equivalent).
Acoustic signals can be examined using less calculation power, compared to image analysing techniques, a sequence of images, or techniques using more sensors. We suggest using acoustic sound processing techniques that analyse signals recorded from fixed microphones located along the track. Placing an acoustic data relieving station near the pantograph of every train would allow measurements to be more direct and continuous, but on the other hand installation, maintenance, and control costs would be higher.

3 Preliminary Considerations

For a diagnostic test, apply a stimulus of characteristic parameters (programmed or natural) then get characteristic parameters coming from signals generated from internal excited sources. Often sources are damped oscillators: frequency and reduction constants depend on activated sources resonant characteristics.
When the contact wire that scrapes across the contact strip on the surface of the pantograph meets a rut it produces a “whiplash”, which is considered as a “stimulus” on the pantograph. Whiplashes can be of different force – it depends on whether the surface is homogeneous or not – they make the pantograph vibrate in a range of different frequencies within a defined band and with constant definite damped time that can be described as a vibro-acoustic “activated source”.
As the contact wire is zigzagged, the sequence of the whiplash is determined by the train’s speed, and by the distance between the ruts on the surface of the pantograph. (contact strip).
The of stimulated vibration frequency (usually between 6000 and 8000 Hz, as experimentally determined) are hundreds of times greater than the frequency of signals modulated by roughness (zigzag cycle), i.e. stimulus frequency.
Sound intensity, with irregularities at 1 cm from each other, on a train travelling at 100 Km/h (27,7 m/s) and with 0.4 m transversal fluting every 45 m, is modulated at a frequency of few Hz. [10]
After these considerations and wide-ranging experimental evidence, the data signal processing technique has been put into practice as described.

4 Signals Registered At “Casilina”- Railway Station In Rome

The correct set up of measuring system and standard properties of the railway system is essential for the quality and amount of information that is obtained by generated and acquired signals.
The acquisition station next to the railway station Casilina, in Rome (on the peculiar track Formia-Naples line) monitored the pantographs in transit along a platform (a short track between two consecutive poles) with the flowing features:

- Set in a straight line, distance between poles reduced to 45 meters;
- Catenary is made up of supporting rail and two contact lines;
- suspensions are the longitudinal ones;
- zigzag and standard droppers ;

The acquisition system is made up some elements:
1. Two directional microphones, with wide operational frequency (20 Hz ÷ 20 kHz) and low overall harmonic distortion, constitutes the apparatus sensors. The microphones are placed at about the same height as the contact wires in order to reduce the distance between sensors and line. The first microphone is placed near the first pole, and the other in middle of the platform, both turned at 30° respect to the train’s normal travelling direction line. This set up allowed us to observe the scraping under high intensity and for longer periods, allowing the phenomenon to be observed along the whole pantograph surface;
2. An automatic trigger, effected by a pair of sensitive photocells, checks train transit and starts acquiring data;
3. A signal conditioning block made with a double channel amplifier, one for each microphone, and a low-pass filter that increases the intensity of signals to acceptable levels and eliminates any problems of aliasing bound to the next A/D conversion;
4. A data acquisition card (DAQ) with a 16-bit resolution and 0-5V input range, operates signal conversion A/D to 44100 Hz sampling frequency;
5. A laptop, with powerful acquisition software, that controls the fore-mentioned card and registers the acquired signals on a hard disk. Recording time is about 23 seconds.
6. A second pair of photocells to determine speed of passing train.

5 Data Acquisition

In the following pictures you can see some of the signals that were recorded at the station Casilina (diagram of time- amplitude signal is also given).

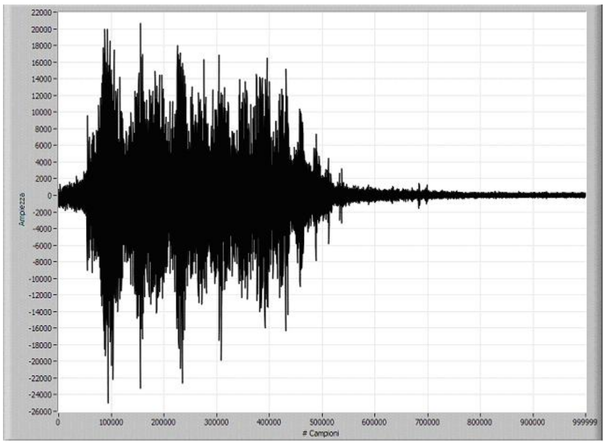

Fig.1 Acquisition channel 0

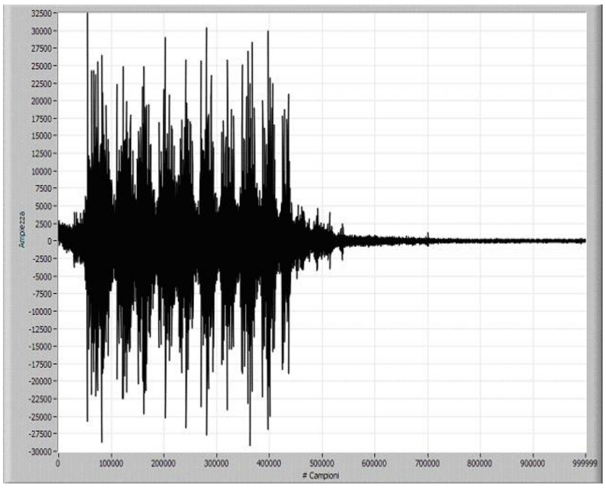

Fig.2 Acquisition channel 1

6 Signal Analysing Process

6.1 Pre-filtering

First step is reducing analysis to the recorded segment related pantograph passage reducing the computing time. To this goal, you must carry out a space discrimination (using directional microphones) and frequency screening.
A mathematical model could be made to represent the detailed structure of the pantograph, then determine frequency and typical damping constants through simulations. However, this is not practical due to the different types of pantographs being used.
On analysing hundreds of records, we found that pantographs used on fast trains (v>100 Km/h) generally emit noise within the band 6-8 KHz. This approach allowed us to analyse the different types of pantographs in use with the same technique.
Time interval corresponding to the passing pantograph is determined analyzing spectrogram of the whole recording; as seen in Fig.3. [11]

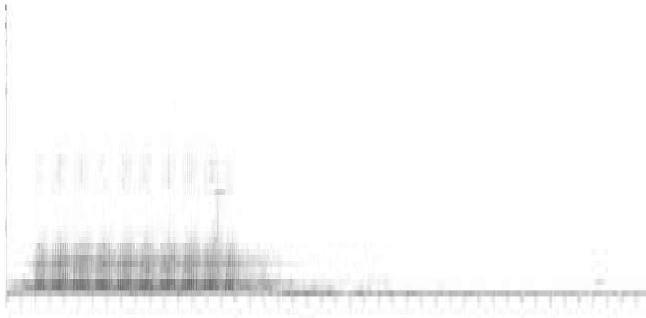

Fig.3 Spectrogram of passing train

6.2 Numerical Application Method

Wavelet transform algorithm with the sample signals was adapted to make a well-matched analysis to the frequency range that must be dealt with.
The following procedure is suggested to extract from the signal, sampled in constant temporal intervals equal to **τ,** the parameters connected to the emission spectrum of "sources" in the pantograph, useful for characterizing the state of the same.
The interpolative process developed could seem obvious. $\left|s\right\rangle$ stands for some values pointed out in the N samplings of the signal that is vector to N components equal to s_1, s_2, ..., s_i, ..., s_n .
$\left|w\right\rangle$ represents the string of g values of all the parameters that characterize the mother wavelet with $g << N$. These make up the coefficient of a vector w_1, w_2, ..., w_i, ..., w_g . Normally the relationship is $\sum_{i=1}^{g} w_i = 0$. The coefficients are taken as the system of set values from the mother wavelet to a temporal τ interval.
The method is as follows:
Once j_0 is fixed they form sub-aggregates of the entire aggregates of the whole set of sampling values $\left|s\right\rangle$ made up by sequences of samplings in numbers equal to
g + k: s_{j_0}, s_{j_0+1}, ..., s_{j_0+g}, ..., s_{j_0+g+k} that will be referred to and indicated to as vector $\left|s\right\rangle_{j_0,k}$.
The number of sub-aggregates possible, like those indicated, is equal to:

$$(N-g)+(N-g-1)+\ldots+(N-g-k)=n_{totale}$$

.
To take out the $\left|s\right\rangle_{j_0,k}$ projection on the mother wavelet expanded and metaphorical, a difficulty that arises because by fixing j_0 we must project a vector of $g+k$ components on a g component vector. If the

wavelet were expressed with an analytic function, expanding it, i.e. varying k of a $\frac{g}{g+k}$ factor, and interpolating it, we can extract $g+k$ values and obtain a vector associated to the wavelet $|w\rangle_{g+k}$ on that project $|s\rangle_{j_0,k}$.

The equation is: ${}_{g+k}\langle w|s\rangle_{j_0,k} = A_{j_0,k}$.

We do not however have an analytic expression for the wavelet, therefore to extract $g+k$ values we should proceed with interpolation processes.

Our method avoids this interpolation process using an alternative analytical process that gives the same result.

By fixing j_0, $j_0 \cdot \tau$ it acquires a temporal flow meaning of wavelet on *N* samplings aggregate.

Fixing k, $(g+k)\cdot\tau$ it gets a temporal meaning of expansion of the wavelet, or in other words lessening, in the ratio of $\frac{g}{g+k}$, of base frequency used for analysing the signal.

We then continued by building all the possible sequences of g elements from the aggregate $g+k$ of samplings.

If $k=1$, the only sequences is g, but if k increases, the number n_k of sequences start to increase disproportionably in relation to $k!$.

$|s\rangle^{P}_{j_0,k}$ indicates a generic sequence among those possible, $1 < P < n_k$ being the generic indicator that designates them.

The coefficient obtained from the projection of the wavelet on the $g+k$ segment values is obtained through the following formula:

$$\frac{\sum_{P=1}^{n_k} \langle w|s_g\rangle^{P}_{j_0,k}}{n_k} = \overline{A}(t = \tau \cdot j_0, \omega_0 \frac{g}{g+k})$$

where ω_0 stands for: $\omega_0 = \frac{2\pi \cdot \nu}{g\tau}$, with ν equal to the number of positive and negative alternations in the wavelet values.

To avoid a complicated computing process we continued by making a limited number (eg. up to 100) of ordered sequences, drawing out them out at random

In the case of pantographs analysis we proceed by applying the process repeatedly and for the requested of translation and expansion parameters. As final results a *N x k* matrix was obtained.

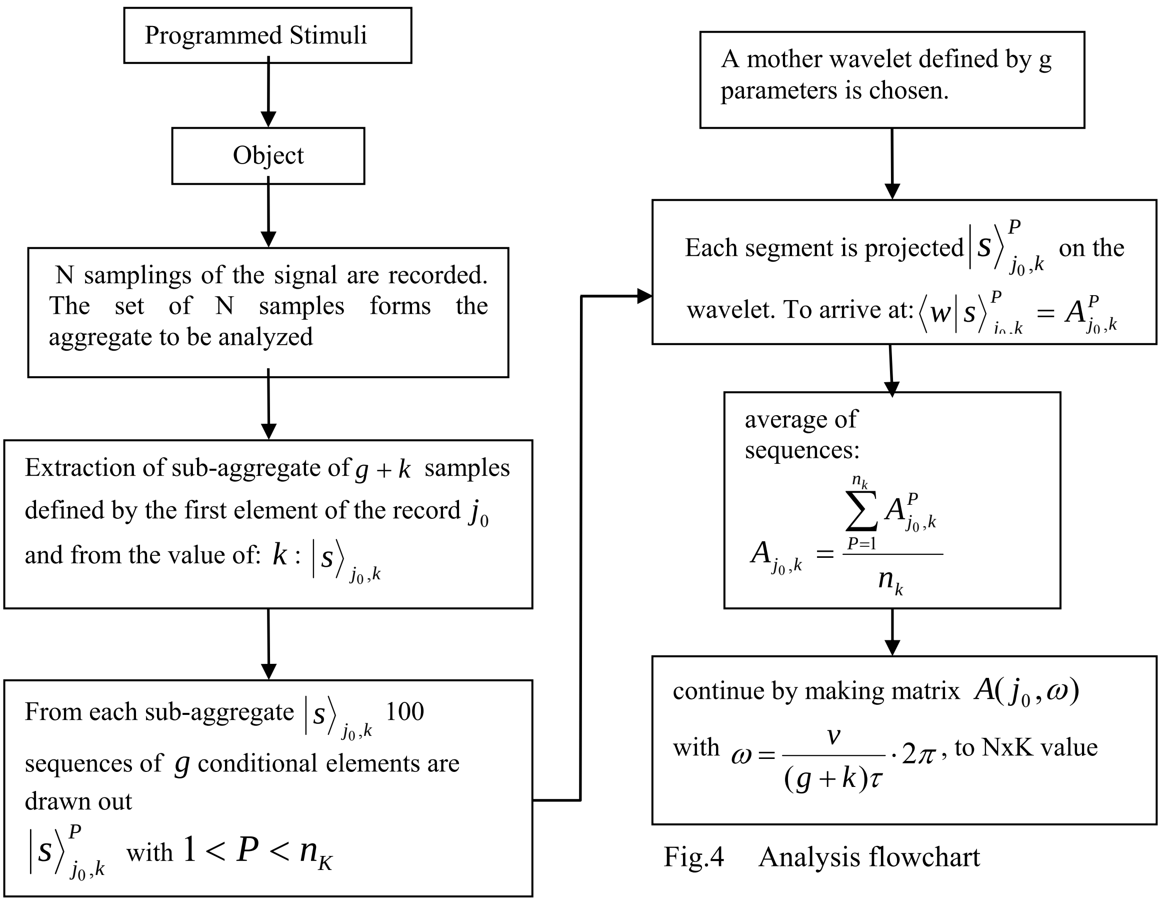

Fig.4 Analysis flowchart

Obviously an appropriate choice of g coefficients defining the mother function is fundamental. [12] [13] [14]
Bearing in mind the damping time of the vibrations caused by the cable on the contact strip is tens of times greater than sampling time τ , the choice of wavelet tends to a function with slight oscillation course.
Values of "expansion" parameter k are :

$$k = \nu \cdot \frac{f_c}{f} - g$$

where ν stands for wavelet alternations, f is the frequency to be analyzed, f_c is the sampling frequency and g is the number of coefficients that define wavelet.

6.3 Meaningful parameters extraction

To determine the coefficients that characterise the state of a pantograph we calculate the envelope vector by finding the average of every sample on k values used. This yields a N component vector. As we have to make a "profile-meter" with a resolution called Δs, we get : $\Delta s = v_{TRASV} \cdot \frac{1}{f_T}$ where v_{TRASV} is speed at which the contact cable point moves transversally on the contact strip, and f_T is low-pass filter frequency cut-off point that generates the envelope. Logically f_T is not fixed but depends on the train's speed.
The result again is an N components vector (Fig.5).

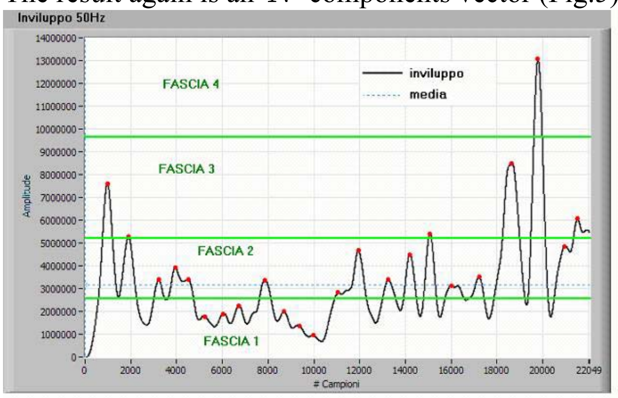

Fig.5 The envelop

Envelope analysis:

- calculate the average value of the envelope
- determine relevant maximums (excluding any values that crop up from defects in the line)
- compare every maximum to the mean determining the appropriate band $1,2,\ldots,N$
- allocate an appropriate weight to every band $p_1, p_2, \ldots, p_N$
- a coefficient $R = n_1 p_1 + n_2 p_2 + \ldots + n_N p_N$ is calculated where $n_1, n_2, \ldots, n_N$ are the number of the relevant maximum included within bands $1,2,\ldots,N$

R stands for "roughness coefficient". A higher value denotes a higher level of irregularity on the contact strip.

7 Presentation of some Analysis

In the case of wavelet used to analyse the signal in range of frequencies between 6-8 KHz, use values for k range from:

$$k_{START} = \nu \cdot \frac{f_c}{f} - g = 4 \cdot \frac{44100}{8000} - 8 \cong 14$$

to:

$$k_{END} = 4 \cdot \frac{44100}{6000} - 8 \cong 21$$

If a train transits at 100 Km/h, to check irregularities in the range of 0.5 cm you get:

$$\Delta s = v_{TRASV} \cdot \frac{1}{f_T} = \frac{0,4}{45} \cdot v_{TRENO} \cdot \frac{1}{f_T}$$

$$f_T = \frac{0,4}{45} \cdot 27,78 \cdot \frac{1}{0,005} \cong 50Hz$$

Positioning bands of belonging, as in Fig.5, and taking $p_1 = 0,5 \quad p_2 = 1 \quad p_3 = 3$
for the weights, we got some important results.
The Following picture (Fig.6) is a pantograph still in standard condition: when the method was applied it gave a coefficient $R = 16$.

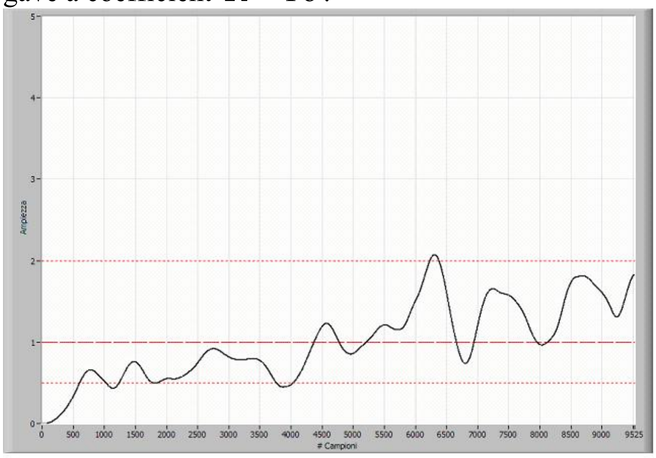

Fig.6 Pantograph in standard condition

But when the same method was applied to a pantograph with worn contact strip (Fig.7) we got coefficient $R = 36$ in return.

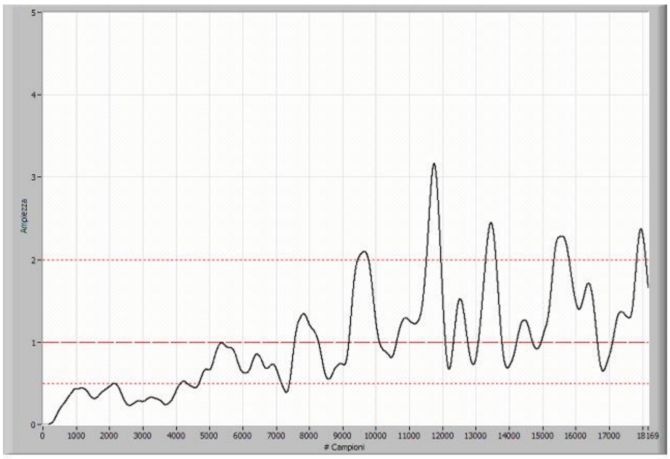

Fig.7 An worn pantograph.

8 Conclusion

After several sessions spent on data acquisition for analysing noise made when a contact wire touches the contact strip line when a train passes, we find out to elaborate the signal to determine roughness on contact strip. If there is any deformity along the contact strip surface, the contact wire generates additional oscillations in the form of whiplashes, which produce vibrations in a range of thousands of hertz more than frequencies generated by a "healthy" contact strip. The frequency signal level is affected by the distance between irregularities present on the pantograph; while the signal frequency is proportional to train speed. The speed of transversal crawling depends on the zigzag of the aerial line. Usually, on a train travelling at 100 km/h, the contact point between the pantograph and aerial line moves horizontally across the surface of the pantograph at a speed of tens of cm/sec.

If power envelope of signal is developed with low-pass filter, elaborated to tens of Hz, it underlines roughness with cadence even below one cm.

The validity of the suggested pantograph is valid although there still remains a margin of error because the device is not entirely capable of filtering noise coming from other sources.

Although there are some limits, this signal processing technique offers a preliminary diagnostic service that warns you if the pantograph at the first station where the train is due to arrive needs to be mechanical controlled. This type of data acquisition station, integrated with online data communication equipment and a data elaboration module, is not very expensive and installation is simple and non-invasive.

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