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# Detection of singular contact wire wear patterns at span scale by dimensionality reduction

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## Abstract

Over the electrified rail network, the wear of the contact wire is caused by a variety of physical phenomena (e.g., mechanical, electrical, thermal). The monitoring of the thickness of the wire is mandatory to prevent catenary incidents and to plan relevant maintenance operations. However, even if wear is generally unavoidable, in certain cases the overhead contact line (OCL) can end up in a configuration favourable to wear, accelerating the phenomenon. In these cases, wear may be mitigated by appropriate OCL adjustments.

This paper presents an approach to distinguish common wear, assumed to be inevitable and therefore not requiring specific adjustment, from the singular wear, which may be mitigated by appropriate adjustment of the OCL. The scale of interest is the span at which similar wear profiles are expected to be observed.

We propose a two-step approach consisting, first, in a dimensionality reduction of the contact wire thickness measurements at the span scale, then in the analysis of the residuals to classify the wear pattern between common and singular. Two dimensionality reduction methods are assessed: the principal component analysis and the non-negative principal component analysis.

Such a method aims to help to better handle maintenance and design operations. It allows to focus monitoring and maintenance efforts on locations classified as singular,

meaning where the future wear or the risk of catenary incidents could be promisingly reduced.

**Keywords**: overhead contact line (OCL), contact wire wear, catenary maintenance, dimensionality reduction.

# 1 Introduction

In France, although only half of the railway network is electrified with two coexisting electrification systems, AC 25 kV and DC 1.5 kV, the corresponding traffic accounts for ninety percent of the total. Catenary incidents (around 400 annually), including contact wire breaks, may highly perturb train operations, causing up to thousands of hours of yearly delays. Therefore, a careful monitoring of the contact wire is crucial to prevent and reduce the occurrence of such events. Automated measurements of the contact wire thickness are periodically performed by inspection trains in order to anticipate its replacement or plan overhead contact line (OCL) adjustment when required. However, monitoring and maintenance operations are limited for economic and logistical reasons. In 2020, SNCF expenses for the renewal of the catenary systems were around 150 M€ [1].

Wear of the contact wire stems from a variety of physical phenomena (e.g., mechanical, electrical, thermal) as experimentally observed [2] and it cannot be avoided. Faster wear is observed on the DC 1.5 kV system, which is the focus of this study, due to a higher current intensity and specific pantograph contact strip materials. One of the main sources of wear is the slow abrasion caused by the sliding contact between the pantograph and the contact wire. In most cases, there is no need for intervention to adjust the catenary system since wear is inevitable and known as common. However, in some other cases, the mechanical system changes over time and may end up in a wear-favourable configuration, inducing accelerated local wear. In these cases, the wear, regarded as singular, may be mitigated by means of OCL adjustments. In these cases, the wear progression is considered as singular. Proper classification of wear progression, common vs. singular, could lead to a bespoke maintenance procedure.

In this paper we propose a methodology to prioritize the maintenance operations within the existing processes. First, we describe a data analysis method to distinguish common wear patterns from singular ones in order to assist the decision-making process. Then, we describe and discuss the results of the proposed method. Finally, we share the perspectives of our work.

# 2 Methods

The raw data consists of 5-years contact wire thickness measurements recorded on the DC 1.5 kV system and sampled every 2 cm (Figure 1). The annualized contact wire wear is then derived from thickness measurements.

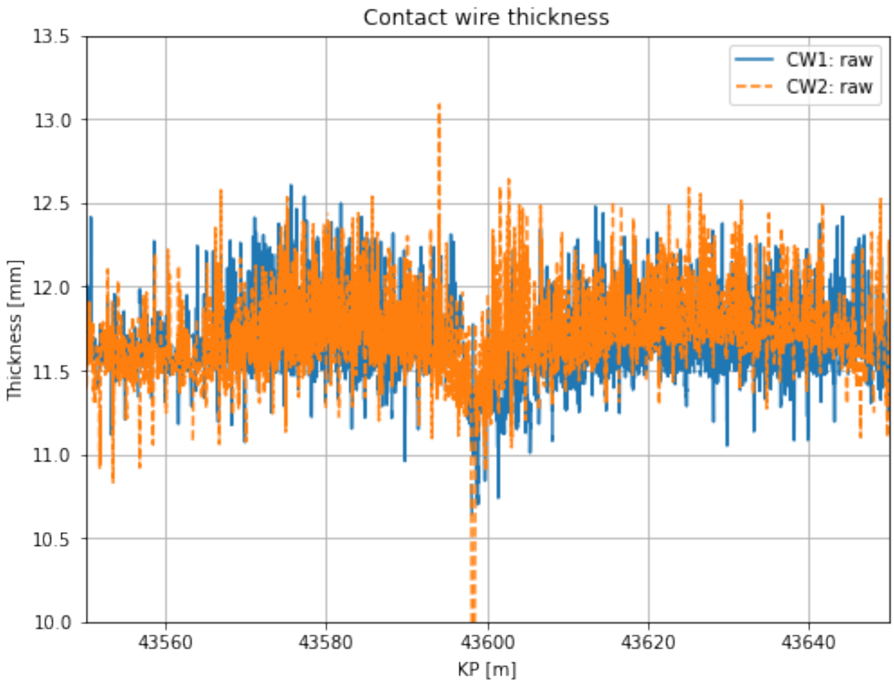


Figure 1: Raw contact wire thickness measurements – the 2 curves represent the thickness along the 2 contact wires of the SNCF DC 1.5 kV catenaries.

Over the 1.5 kV network, similar contact wire wear patterns are expected to be observed at the span scale (i.e., between two consecutive supports). The wear strongly depends on the contact force applied by the pantograph [2]. In addition, the dynamic behaviour of the contact force is highly dependent on the elastic properties of the OCL as observed both from measurements and numerical modelling [3]. Since all the spans have approximately the same relative elasticity profile, lower near the supports and higher in the middle, the relative contact force profiles are similar between all these spans, leading to a similar span scale wear. The wear, described by a collection of vectors of a few thousand points (e.g., 2501 points sampled every 2 cm for a 50 m span), is then expected to share common behaviour over the network.

To distinguish common wear from singular one, we perform a dimensionality reduction, after resampling the observations on a common basis of 3000 points. The measurements are then decomposed into a linear combination of the low-dimensional basis vectors plus the residuals. The resulting basis retains the most common properties of the original data cutting-off noise and unusual properties. A common wear pattern is expected to be accurately described by this new representation, exhibiting low residuals. Conversely a singular wear pattern is expected to show high residuals. Hence, maintenance operations could be prioritized on spans with singular wear patterns. The choices of the dimensionality reduction method and the number of retained dimensions are essential to accurately distinguish the two wear patterns. Two techniques are investigated to build the low-dimensional representation: the principal component analysis (PCA) and a non-negative principal component analysis (NN-PCA) [4]. Unlike PCA, the NN-PCA method delivers a positively defined basis throughout the domain which is more intuitive to interpret due to the nature of the measurement, wire material can only be lost.

The analysis of the residuals, by means of a chosen norm, allows to classify the measurements: the common wear patterns with low residuals and the singular ones with higher residuals.

## 3 Results

We process data from around 15000 spans of the DC 1.5 kV network. The first four vectors of the low-dimensional basis, also called principal components (PC), obtained from the two methods (PCA on the left and NN-PCA on the right) are displayed in Figure 2. The abscissa corresponds to the normalized rescaled span lengths. For each PC, two profiles can be observed corresponding to the two contact wires of the OCL designs. Contrary to the PCA basis, the second results could be different since they depend on the random matrix initialization and an arbitrary number of components.

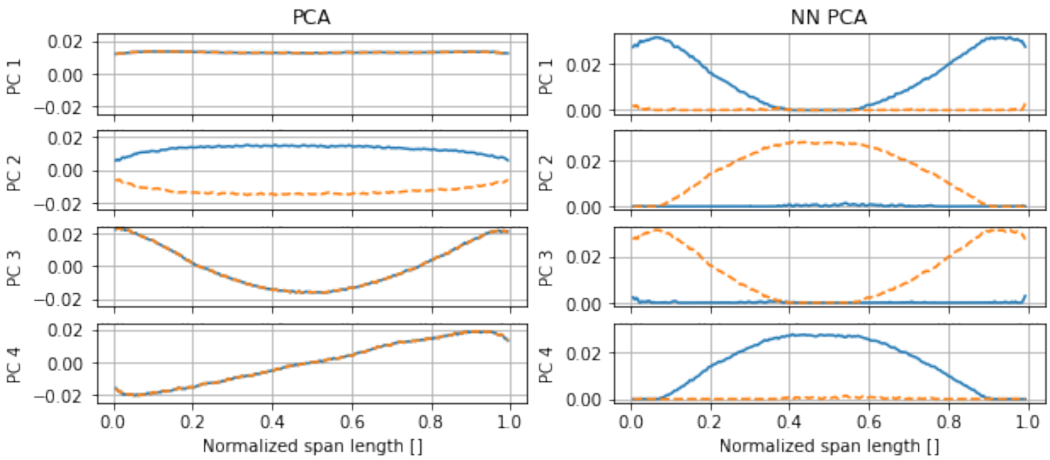


Figure 2: The first four PC obtained by means of the PCA (left) and the NN-PCA (right).

The PC of the PCA are prone to physical interpretation. The first one exhibits a constant wear over the entire span. It is highly correlated with the traffic. The second one shows an opposite behaviour between the two contact wires and is significantly correlated with the track curvature. The third one is a commonly observed behaviour where the wear progression between the support and the middle of the span are opposed, probably due to the dynamic behaviour. However, surprisingly, the principal components computed by means of the NN-PCA seem less interpretable. Consequently, the PCA is considered throughout the rest of the study.

The first principal components represent a common wear pattern as they generalize to the entire network. A higher order component with high frequencies may correspond to a particular geometrical configuration as illustrated in Figure 3. On top, a principal component with the auxiliary dropper locations is shown, and on bottom the corresponding Fourier transforms, as well as the auxiliary dropper frequency. The considered PC is then a characteristic of a specific configuration and should then be excluded from the desired basis.

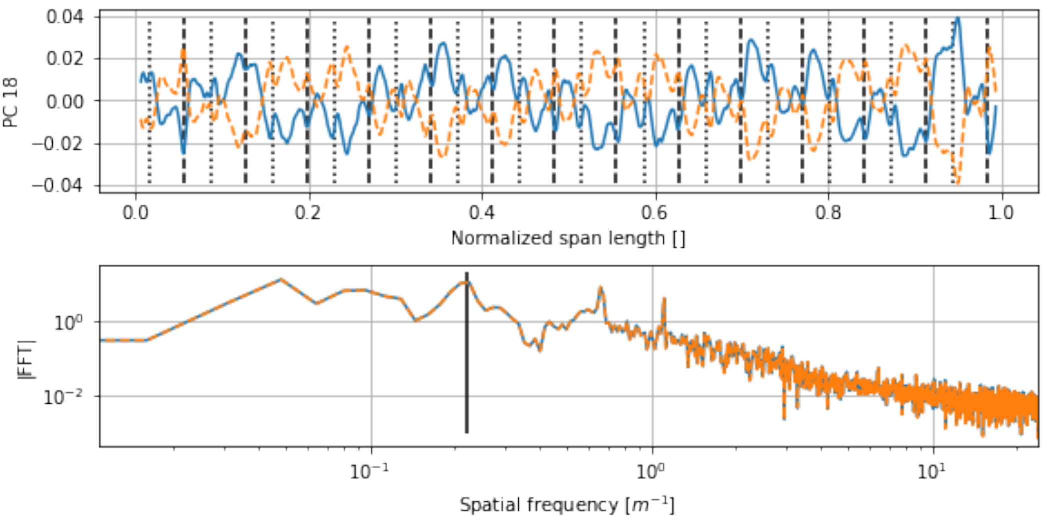


Figure 3: High order principal component (18) (top) and the corresponding Fourier transform (bottom). The vertical lines denote the auxiliary dropper locations (top) and spatial frequency (bottom).

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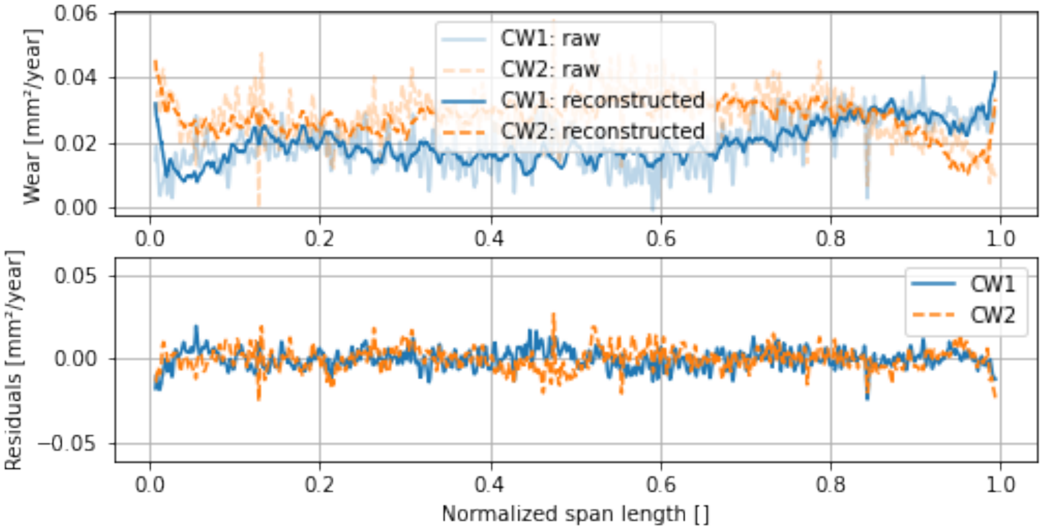


Figure 4: Original and reconstructed measurements along a given span presenting uniform and small residuals.

Using the retained low-dimensional representation, the residuals are computed for all span measurements. Analyses of the residuals allow to distinguish wear that is well reconstructed from the one with high residuals, as illustrated in Figure 4 (low residuals) and Figure 5 (high residuals).

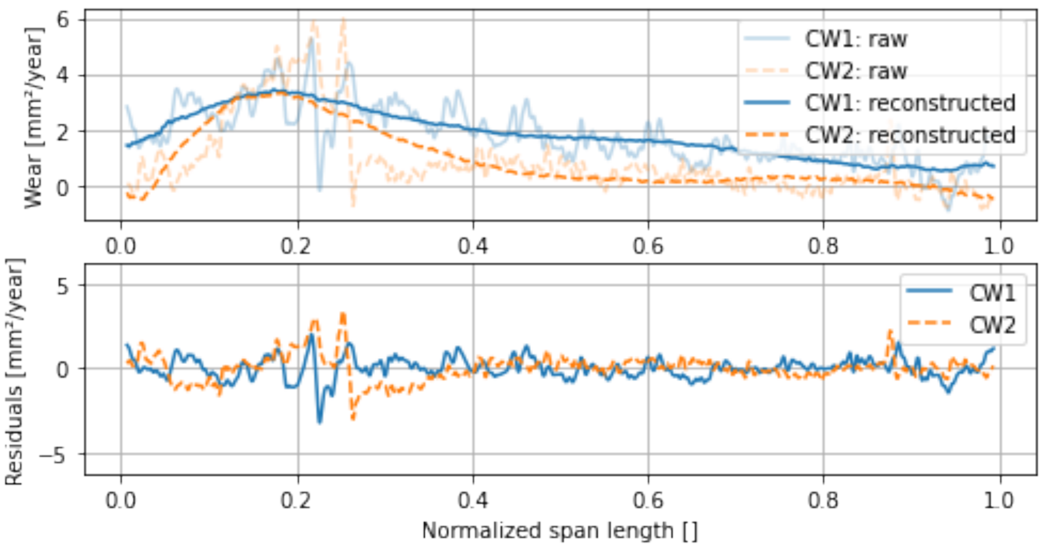


Figure 5: Original and reconstructed measurements along a given span presenting high values close to 0.2.

## 4 Conclusions and Contributions

In this work, we propose a methodology to classify the contact wire wear patterns and better handle maintenance and design operations. It is achieved by applying a dimensionality reduction technique on observed thickness measurements at the span scale.

Two techniques, PCA and NN-PCA, are evaluated. The first one is retained in order to distinguish common wear patterns from singular ones. These two categories are established based on the analysis of the computed residuals; measurements with low residuals are regarded as common wear and measurements with high residuals as singular wear. Further analyses, for instance an additional dimensionality reduction or different residual characterisations, may lead to a finer residual classification. Consequently, monitoring and maintenance efforts could be focused on locations classified as singular, where the future wear or the risk of incidents could be promisingly reduced.

Principal components as well as residuals should be explained by underlying physical phenomena. Therefore, in order to get insight, we intend to further analyse their correlation with a larger set of explanatory variables. The results may provide valuable knowledge useful not only for the decision-making process in the maintenance operations but also for the catenary design office.

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# References

[1] SNCF Réseau. Rapport annuel de sécurité 2020. Public report (2020), url: https://www.sncf-reseau.com/sites/default/files/2021-09/SNCFReseau_RapportAnnuelSecurite_2020.pdf

[2] Derosa S., Nåvik P., Collina A., Bucca G, and Rønnquist A. A heuristic wear model for the contact strip and contact wire in pantograph – Catenary interaction for railway operations under 15 kV 16.67 Hz AC systems. Wear 456-457 (2020). https://doi.org/10.1016/j.wear.2020.203401

[3] Massat J.-P., Balmès E., Bianchi J.-P. and van Kalsbeek G. OSCAR Statement of Methods. Vehicle System Dynamics, 53 (2015) 370-379. https://doi.org/10.1080/00423114.2015.1005016

[4] Giordani P. and Kiers H. A. L., Principal component analysis with boundary constraints. Journal of Chemometrics, 21 (2007) 547-556. https://doi.org/10.1002/cem.1074