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Procedure to assess the role of railway pantograph components in generating the aerodynamic uplift

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ABSTRACT

Aerodynamic forces play a big role in determining the value of the mean force acting between the collectors of a railway pantograph and the contact wire, especially for speed higher than 200 km/h. The contact force has to be properly calibrated in order to have a good quality collection of power and low wear of contact strips and contact wire. This paper analyses the pantograph features that mainly affect its aerodynamic behaviour, and their influence on the mean value of the contact force. Wind tunnel experimental tests on a full-scale pantograph and Computational Fluid Dynamic (CFD) simulations in a wind tunnel scenario are carried out for different pantograph configurations, and the contribution of each different part of the pantograph to the mean contact force is investigated. To this end, the feasibility of using the RANS model and steady state simulations is evaluated.

1. Introduction

In pantograph-catenary operation, the contact force between the carbon strips and the contact wire significantly affects the quality of current collection, as the electrical resistance being inversely proportional to the contact force value. The choice of the mean value of the contact force is a compromise between two different needs: on the one hand, low force values are responsible for arcing, disruption of power collection, and electrical-related wear. On the other hand, high contact force values are responsible for mechanical wear on strips and increased excitation of the overhead contact line, leading to high dynamic oscillation of the force itself and to important stresses on the interacting systems.

International standards for the assessment of the behaviour of the pantograph-catenary system (e.g. TSI, the EU's Technical Specifications for Interoperability) prescribe limits to the mean value and the standard deviation of the contact force, the latter being strongly dependent on the dynamic interaction of the pantograph-catenary system. Contact force variability should be mitigated as much as possible, in order to avoid low and high contact force peaks. Great efforts have been made in the last decades to optimise the mechanical interaction between pantograph and catenary, by means of modifications to the infrastructure, the optimisation of the pantograph dynamic response, and the fine-tuning of operational parameters. Numerical simulations of the dynamic interaction between pantograph and catenary were instrumental for these goals (Zhou and Zhang, 2011). Simulations are nowadays based on models and features that are shared and agreed-upon within the scientific and technical international communities (Bruni et al., 2015). This is so well established today that researchers and international studies have moved their focus to the issue of virtual homologation, with the aim of assessing the dynamic interaction of the pantograph-catenary system by means of numerical simulations and laboratory experiments, such as Hardware-In-the-Loop tests (HIL) (Resta et al., 2008).

Within this framework, pantograph and overhead line aerodynamics are other important factors responsible for affecting the contact force, both in terms of mean value and dynamic variation (Pombo et al., 2009). This issue is as relevant as the dynamic interaction between pantograph and catenary, even if only more recently investigated in the literature, concurrently with the spread of high-speed railway networks.

Stationary forces acting on pantograph components are able to change the mean value of the contact force, adding their contribution to the uplift force exerted by the pantograph raising mechanism at the bottom of the articulated frame (normally an air spring). This effect, indicated in the following as *aerodynamic uplift*, is dependent on train speed, pantograph working height (Lv et al., 2014) and orientation (modern pantographs have an asymmetrical geometry generating different aerodynamic uplifts in the two orientations in which they can operate). Moreover, the aerodynamic uplift varies when the pantograph enters a tunnel, due to the increase of the velocity of the relative flow. The influence of aerodynamic forces on the mean contact

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force can be so high, especially in the case of high-speed trains, that it is commonly compensated in order to guarantee operational stability. Attempts to balance the aerodynamic uplift by means of aerodynamic spoilers were proposed, but this was not trivial considering that it is very difficult to optimise the spoilers for both pantograph orientations. Therefore, in recent years, the regulation of air-spring pressure as a function of train speed and pantograph orientation has been proposed as a means to compensate for the aerodynamic uplift and to guarantee the best performances in both running directions and at all speeds (Bucca et al., 2012).

Aerodynamic non-stationary phenomena also influence the performance of a railway pantograph, and can be divided into two groups, related to the turbulence of the incoming flow and to vortex shedding. The presence of recesses, coach separation, electrical insulators, switches and other components installed on the train roof generates a turbulence wake, whose frequency spectrum is likely to excite the pantograph structure also within the frequency range set by international standards for the evaluation of the quality of current collection (0–20 Hz in Europe) (Bocciolone et al., 2006). Vortex shedding is generated by collectors of the pantograph head that, due to their rectangular section, can be regarded as bluff bodies (Lee et al., 2009; Carnevale et al., 2016). The excitation of these very high frequencies can also affect the quality of current collection, as demonstrated in (Collina et al., 2009).

This paper proposes a methodology to evaluate the effect that the average drag and lift forces acting on each pantograph part have on the total aerodynamic uplift, not dealing with non-stationary effects.

Aerodynamic uplift needs to be taken into account in pantograph design, in order to minimise its value and its variability in the two orientations in which the pantograph can operate. In this context, the possibility of distinguishing the contribution of each part and the influence of different design solutions to the total aerodynamic uplift is very important. In current design, railway pantographs are based on a one-degree-of-freedom mechanism, named *articulated frame*, which is essentially a four-bar-linkage. Drag and lift forces acting on pantograph parts tend to open or close the mechanism, and have an influence on the total aerodynamic uplift, depending on the Jacobian terms defining the virtual work that each force is able to produce. The effect of each force to the total aerodynamic uplift can be therefore evaluated through the application of the virtual work principle.

In this work, CFD simulations are validated by means of the comparison with wind tunnel tests, and exploited to evaluate drag and lift forces on pantograph components, to be used as an input for the application of the virtual work principle. The experimental evaluation of these aerodynamic forces is indeed not feasible in operating conditions on a full-scale train, due to the high number of sensors needed, and not advisable in a wind tunnel, due to the several days of testing required when aiming to evaluate different design solutions. CFD simulations, therefore, become a powerful instrument, allowing the identification of the role played by each pantograph component in generating the aerodynamic uplift, and the evaluation of the aerodynamic uplift force corresponding to different pantograph configurations.

The numerical simulation of pantograph aerodynamics has not yet come to maturity, despite the considerable research that has been developed in past years, and the significant use of CFD and aerodynamic simulations in railway applications (e.g. cross wind, Baker, 2010; Cheli et al., 2010). Experimental on-track tests are still the main instrument not only for the evaluation of pantograph aerodynamic performance during the homologation process, but also for the fine-tuning of the best design solutions. CFD simulations have been performed in literature mainly focusing on the pantograph head (pan-head) and collectors model, in order to study drag and lift forces (Bocciolone et al., 2006) and acoustic emission (Cho, 2008; Ikeda and Mitsumoji, 2009, 2008; Suzuki et al., 2007). With regard to the possibility of estimating aerodynamic forces on the entire pantograph, some authors have developed CFD models of a full-scale pantograph in a domain representing only the part of the carbody roof close to the pantograph (Yao et al., 2011), or CFD models of a pantograph installed on a full-scale train (Luo et al., 2009). In (Lv et al., 2014), the authors underline the variability of the aerodynamic uplift force at different heights for both pantograph orientations, but no experimental results are presented. In (Gregoire et al., 2008), a full-scale pantograph is tested in a wind tunnel and the experimental results are compared with those of CFD models. In all the mentioned works, however, a complete validation of the CFD model against experimental results is not available, so that the capability of CFD to reproduce the aerodynamic uplift in an accurate quantitative way has not yet been completely demonstrated (Li et al., 2014; Lv et al., 2014; Gregoire et al., 2008). In this paper, the feasibility of using the RANS model is evaluated in order to seek the best trade-off between the achievable results and the computational effort, and to formulate a proposal that is also suitable for industrial applications.

The paper is organised as follows: in section two, experimental wind tunnel tests on a full-scale pantograph are described, and the results of different pantograph configurations are shown. In section three, the CFD modelling is outlined, together with the main modelling features and the results of mesh optimisation. In section four, the model is validated against aerodynamic global forces for all the pantograph configurations tested in the wind tunnel (Section 4.1), and thereafter, the procedure for the evaluation of the aerodynamic uplift force based on the virtual work principle and CFD results is described and adopted for all the pantograph configurations tested (Section 4.2). Finally, in section five, the analysis focuses on the role played by each pantograph component in generating the aerodynamic uplift.

2. Wind tunnel characterisation

Wind tunnel tests are a useful tool for a first assessment of the aerodynamic properties of a pantograph. Indeed, they highlight possible criticalities and enable the attainment of indications on the countermeasures needed to achieve the target contact force at every speed with a newly developed pantograph, before aerodynamic on-track tests are carried out. Their drawback consists in the need to reproduce the actual boundary layer of the train roof in order to obtain aerodynamic forces comparable, also quantitatively, to those encountered in operation on a full-scale train. In (Takaishi and Ikeda, 2012), the authors propose a feasible way to reproduce the full-train boundary layer in a wind tunnel. However, the proposed method still needs experimental on-track tests in order to tune and validate the shape of the obstacles generating the boundary layer. As an alternative, CFD simulations can be used to extend wind tunnel results to the real operating scenario (Carnevale et al., 2015). To this end, it is extremely important to correctly reproduce the forces acting on the single elements. Wind tunnel results are used therefore, as in this work, for a preliminary investigation of the aerodynamic properties of the high-speed pantograph under analysis, and as a reference to tune and validate the CFD model. The CFD model validated by wind tunnel experiments can then be extended to simulate the full-train scenario, in which the boundary layer of the train roof alters the average aerodynamic forces acting on the lower parts of the pantograph, mainly due to the reduced velocity of the incoming flow.

The wind tunnel tests were performed at the Politecnico di Milano in the high speed, low turbulence test section, whose main characteristics are reported in Table 1. The test section can be used for pantograph applications in either open or closed configuration.

For the pantograph used as a reference in this work, the tests were performed in the closed test section, the blockage ratio being around 3%. The pantograph adopted is a modern asymmetrical pantograph, with the lower articulated frame composed of a single cylindrical arm ending with a fork, and the upper part of the articulated frame