Transportation Research Part D 47 (2016) 299–322

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Development of driving cycles for electric vehicles in the context of the city of Florence

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ARTICLE INFO

Article history:
Available online 21 June 2016

Keywords:
Driving cycle
Grouping
Speed
Electric vehicles
Regeneration
Random walk

ABSTRACT

Strong efforts are spent in automotive engineering for the creation of so called Driving Cycles (DCs). Vehicle DC development has been a topic under research over the last thirty years, since it is a key activity both from an authority and from an industrial research point of view. Considering the innovative characteristics of Electric Vehicles (EVs) and their diffusion on certain contexts (e.g. city centers), the demand for tailored cycles arises. A proposal for driving data analysis and synthesis has been developed through the review and the selection of known literature experiences, having as a goal the application on a EVs focused case study. The measurement campaign has been conducted in the city of Florence, which includes limited traffic areas accessible to EVs. A fleet of EVs has been monitored through a non-invasive data logging system. After data acquisition, time-speed data series have been processed for filtering and grouping. The main product of the activity is a set of DCs obtained by pseudo-randomized selection of original data. The similarity of synthetic DCs to acquired data has been verified through the validation of cycle parameters. Finally, the new DCs and a selection of existing ones are compared on the basis of relevant kinematic parameters and expected energy consumption. The method followed for the creation of DCs has been implemented in a software package. It can be used to generate cycles and, under certain boundary conditions, to get a filtered access to the measured data and provide integration within simulation environment.

Introduction

A DC can be considered as a part of a standardized procedure aimed to evaluate and compare vehicle performances in a reproducible way under controlled or laboratory conditions, such as simulation environment, power-adsorbing chassis dynamometer, testbed and sometimes road track. It has to include a time–vehicle speed signal as main input data, but a large set of boundary conditions can be also defined: dynamometer settings, gear shifting points, reference atmospherics conditions, vehicle conditions (tyre pressure, lighting, oil viscosity, transported mass...), cold start conditions (critical, for different reasons, both for ICE and EV vehicles) and any other parameter influencing the performances of the product under test. International standardized procedures are used to assess vehicle performances such as fuel/energy consumption and air emissions; the results are used to verify compliance with reference thresholds and to compare different vehicles.

According to the large variations in terms of driving habitudes, user needs, road characteristics and others it is known that the exact duty cycle to be satisfied during the life of a certain vehicle is not fully predictable. It is therefore probable that a

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http://dx.doi.org/10.1016/j.trd.2016.05.010
1361-9209/

Table 1
Summary of terminology used in the article.

Terminology	Definition
Use pattern	Characteristics of vehicle use including driving profile together with additional information related to charging, load, environment and/or any other factor influencing vehicle performance and durability
Driving cycle	Set of data points representing vehicle speed versus time. Adapted from (Schwarzer and Ghorbani, 2013)
Duty cycle	Set of data points representing power demand versus time. Adapted from (Schwarzer and Ghorbani, 2013)
Driving profile	Collectivity of all driving cycles in a lifetime of a vehicle. Adapted from (Schwarzer and Ghorbani, 2013)
Driving sequence	Time-speed vector consisting of all data points between two relevant events (e.g.: trip – driving sequence between vehicle key-on/key-off events; microtrip: driving sequence between two idle phases)

single DC cannot represent the real driving profile (see Table 1), that includes all the possible conditions on which the vehicle could be used during its life; a compromise is needed.

Despite of the fact that the research and the standardization process started in the early 1970s, the creation of DCs is still a topic under development in scientific and technical literature.

The aim of the activity presented in this paper is to propose a group of driving cycles addressed to EVs simulation and testing; the study includes the definition of a procedure for driving cycle definition and the description of its application on a case-study. The document is structured as follows: Section 'Introduction' introduces the topic, proposes a brief review of literature information and recalls state-of-the-art experiences; Section 'Development of driving cycles' deals with the definition of a procedure for data analysis and cycle synthesis; Section 'Case study: the city of Florence' describes the tailored approach developed and its application to a real case study, including data acquisition on the city of Florence (Italy). Finally results and conclusions are presented.

Driving cycles

In the legislative context, type approval procedures include scheduled tests over standardized DC. The assessed parameters are mainly related to the evaluation of the environmental impact of the vehicle; in case of ICEVs the attention since the early 1970 years has been focused on air pollutants and, recently, on GHG emissions, according to Regulation EC No. 443/2009. A large number of driving cycles are used worldwide for homologation: e.g. EU cycles, US cycles, Japanese cycles and many others (Barlow et al., 2009). Legislative ones also differ on the basis of the class of the vehicle to be tested; main procedures have been defined for M-class passenger cars, light or heavy duty N-class vans or trucks. L-class vehicles such as quadricycles (distinguishing between low and full power ones) and motorcycles are also homologated through appropriate DCs. These cycles often include more subphases which are aimed to represent low and high speed sequences, or, from another point of view, different driving areas such as urban, rural or motorway roads.

As explained since the presentation of early research articles on the topic, DCs are built on the basis of real-world measurement processing (Kenworthy et al., 1992; Lyons et al., 1986; Newman et al., 1992). Depending on the resolution used to describe the synthetic cycle, the driving sequences can include or not the irregularities in speed which are typical of real-world driving by the users; as an extreme, smoothing and decimation of data curves can result in driving sequences composed by straight lines on the time-speed charts, thus corresponding to constant or zero acceleration phases. The widely used NEDC cycle is one example of such approach, even if the newly defined WLTC cycle (UNECE, 2015) is going to be used for type approval on next years. The aim of the introduction of the new procedure is to improve the representativeness of tailpipe emissions and fuel consumption assessments. Recent literature papers on the topic agree on the opportunity of such introduction (Demuynck et al., 2012; Sileghem et al., 2014; Weiss et al., 2012).

Experiences in applied research show that customized cycles are used as input for virtual and testbed testing procedures during product development. A large number of parameters influence vehicle energy consumption and the related emissions, including driver capabilities, driving context, traffic conditions, ambient temperature, etc.: such a variability causes the need for extensive testing on the road of any kind of vehicle during its final development phase. One of the outcome of on-road driving is the definition of tailored DCs which are complementary to legislative ones and can be used to perform additional testing and simulation activities in a reproducible way. Such custom cycles are continuously developed; using appropriate parameters to evaluate the characteristics of driving cycles, in fact, the evidence explained in literature is that local or regional conditions can differentiate driving patterns depending on the area under examination (Lin and Niemeier, 2003; Wang et al., 2008).

The cycles can be defined depending on:

- Load (including continuous or transient speed phases).
- Context of applicability (urban, extra urban, motorway).
- Expected vehicle mission profile (e.g. private passenger use, freight delivery, bus service, etc.).

Car manufacturers usually perform activities on driver and cycle characterization in order to improve their own knowledge on representative test sequences, both using methods for driving cycle synthesis after acquisition on real-world use