A Method to Analyze Driver Influence on the Energy Consumption and Power Needs of Electric Vehicles

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***Abstract*— The energy consumption and power needs of electric vehicles are evaluated on roller test benches according to test procedures defined by legal standards and by vehicle manufacturers. These test procedures are mainly defined by driving cycles and include tolerances to compensate for the human error during these tests. These tolerances may seem to make the tests easier but they can have a big effect on the appropriate dimensioning of the components, and also on the performance of the vehicle. Within this paper, a method is presented, which enables the quantification of these effects depending on the type of the test procedure, and the way the driving cycle is driven. The developed method has been tested in a simulation environment and several standard test procedures were analyzed.**

Keywords*— Electric Vehicles; Driving cycles; Test Procedures ; Energy Consumption; Power needs.

I. INTRODUCTION

One of the methods to evaluate the efficiency and consumption of vehicles is using standardized test procedures. The test procedure consists of a driving cycle. This driving cycle is basically a speed profile that a test driver has to drive. A standard procedure is simplified as follows. The vehicle to be tested is mounted onto a roller test bench. On a screen called "Driver's Aid", the driver is shown the given cycle (speed profile) and the tolerance band. The tolerance band defines the allowed deviation from the given speed profile during the procedure of driving a test cycle (tracking). The driver is additionally shown his actual speed which he then tries to keep inside the tolerance band while tracking. At the end of this test, the relevant values of interest that define the efficiency of the vehicle are measured or calculated.

II. STANDARD TEST PROCEDURES

Each standard procedure defines its own tolerance band. Depending on how the driving cycle is driven within this tolerance band, high power demands might exceed the limits of the components of the Electric Vehicle. In this paper a method to modify the test driving cycle is explained. This modification models the deviation a driver might make within the tolerance band. Several types of drivers were analyzed. This modified driving cycle is then used to analyze the power demands and the efficiency of the vehicle. The need for this method is to analyze what kind of power demands might occur in different driving cycles in order to appropriately dimension the components of the vehicle. This method is then used to analyze the power needs and energy consumption of different standard test cycles in Europe and North America or any given cycle.

Several test procedures already exist: The NEDC (New European Driving Cycle) in Europe [1] and the FTP-75 (Federal Traffic Procedure) in USA [2] .Other standards are also under development such as the WLTP (World Light Test Procedure) adopted by the United Nations Working Party on Pollution and Energy (GRPE) which will soon be ready to be implemented by individual countries [3]

III. TOLERANCE BAND

The tolerance band of any procedure is defined as follows:

(S) (Speed units) higher/lower than the highest/lowest point on the trace within (t) (seconds) of the given time.

Whereas the values of S and t are given for each cycle according to Table I.

The concept can be well understood in Fig.1 from the Code of Federal Regulations (CFR) 2012 .Knowing these values for the studied cycles, the tolerance band for each of them can be constructed.

TABLE I. ALLOWED DEVIATIONS IN CYCLES

cycle	**allowed deviation in**	
	Speed : S	***Time : t (sec)***
NEDC	± 2 (km/h)	± 1 (sec)
FTP-75	± 3.2 (km/h) (± 2 (mile/h))	± 1 (sec)
WLTP	± 2 (km/h)	± 1 (sec)

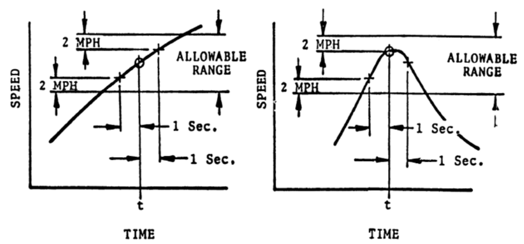

Fig. 1. Construction of the tolerance band for the FTP-75 cycle

IV. Method of Modification

The influence of driver behavior can be analyzed either by generating a modified cycle as done by [4], or by means of a modified driver model. In our case we combined both. We first modified the cycle then applied different driver models.

A. Way Points and Modified Cycle

Any driving cycle consists mainly of the following driving maneuvers:

TABLE II. Maneuver Types

Maneuver	Definition
Acceleration	Positive change in speed
Deceleration	Negative change in speed
Cruising or rolling	Constant speed
Stop	No speed (speed is zero)

The method works by extracting “way points” from the given cycle. Way points are points in the cycle where the driving maneuver changes. Since we have three cycles (lower limit cycle, normal cycle, and upper limit cycle in Fig.2), the maneuvers (phases) in each of these cycles are first identified. Then a cross examination of all three cycles is made in order to select the shortest acceleration or deceleration phase (the period in which all cycles are accelerating or decelerating at the same time) is detected as shown as “combined short” in Fig.2.

This is done in order to find the shortest time that can be used for acceleration or deceleration, which is associated with the highest power demand from the electric vehicle. The rising and falling edges of this combined short cycle are taken as way points and used to construct a modified cycle as shown in Fig.2 for the NEDC cycle.

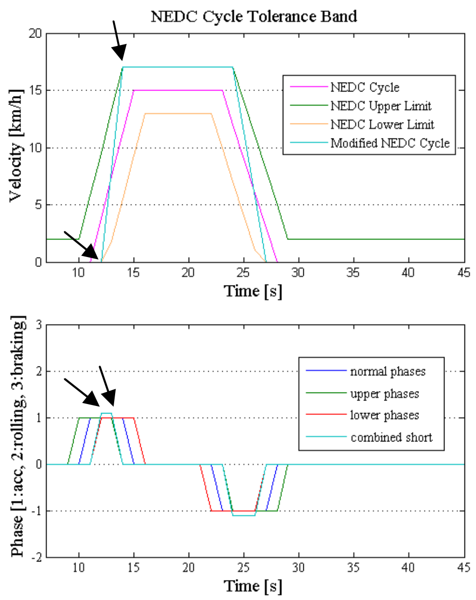

Fig. 2. Applying the modification on part of the NEDC

The method until now works fine with the NEDC because of the relatively simple structure of the cycle. For dynamic and more realistic cycles like FTP-75 and WLTP an additional consideration had to be made. More way points were needed to ensure that the modified cycle stayed in the tolerance band. These additional way points were selected at the points where the jerk (change of acceleration or deceleration during the acceleration/deceleration phases) exceeded a certain threshold limit. This limit had to be determined separately for each cycle because of the different dynamics of each one (Fig.3).

B. Driver Model

After the previously mentioned modification of the cycle, the modified cycle as is leads to very unrealistic changes in speed and accelerations as seen in Fig.5. In order to make the modified cycle more realistic a driver model is needed.

Reference [5] conducted experiments to compare humans and robots driving. ”In contrast to robot drivers, qualified human drivers are looking forward”. They also mentioned that the human driver tries to drive “round and smooth” to avoid hectic changes of the throttle position.

Reference [6] suggests a driver model using a kernel of a special kind. This is done by convoluting a discrete filter (look ahead kernel) with the given speed profile leading to a “smoother” speed profile which is more realistic (Fig.4).

In our case a discrete Gaussian kernel was used in order to simplify the calculations (Fig.6).

It should be noted that due to the properties of convolution, the kernel needs to be first normalized in order to keep the speed profiles amplitude with no change.

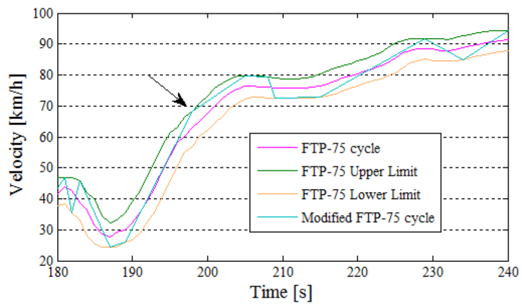

Fig. 3. Additional way point at change in acceleration in the FTP-75

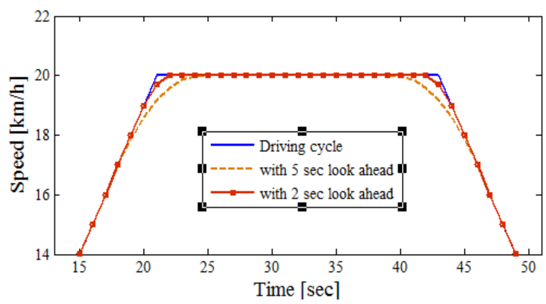

Fig. 4. Concept of driver model with different look-ahead properties

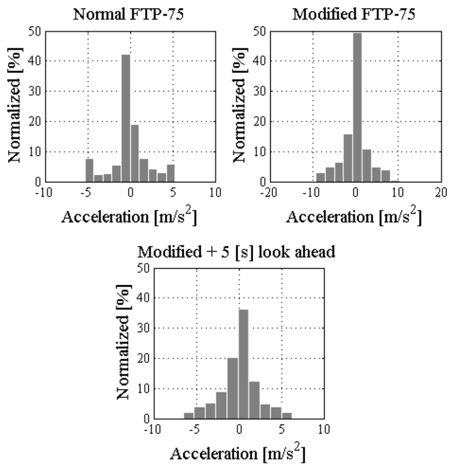

Fig. 5. Histogram of accelerations during different FTP-75 cycles

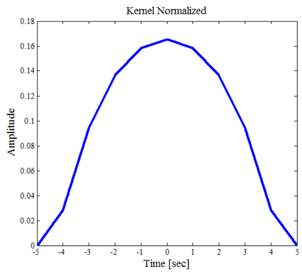

Fig. 6. Normalized Gaussian Kernel

By modifying the width of the kernel in Fig.6, different drivers may be modelled with different look-ahead properties which in turn correlate to the experience level. A 2 sec kernel represents a very unexperienced driver and a 5 sec kernel represents a more experienced driver that takes advantage of the tolerance band (Fig.7).

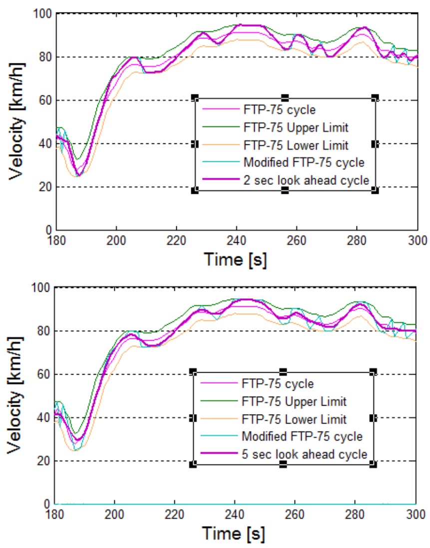

Fig. 7. Comparison FTP-75 with 2 and 5 sec kernel

V. Simulation and Results

All simulations were done using the software CarMaker from IPG. The simulation model of the vehicle was modelled using Matlab/Simulink and was previously validated in [7]. The simulation program offers a speed profile control for the simulation. However, the results were not always reproducible for the same simulation, because the driver model is designed to have some deviations of its own. Therefore a high performance PID controller was modelled [8] and used with the model. This controller allowed the simulation model to track the given speed profile with no deviation at all. All simulations started with 80 % SOC (state of charge of the battery).

Because the dimensioning of the motor is the base for dimensioning most of the other components (especially the battery and the power electronics), the power needs (peaks) of the motor were being analyzed. The SOC level of the battery at the end of the simulation was taken as the measure for energy consumption.

The results of every simulation are compared to the results of the original cycle.

A. NEDC Cycle

The Original NEDC cycle was simulated, as well as the modified cycle without applying any kernel and the modified cycle with 2 sec look ahead kernel.

The results of these simulations are shown in Table III.

B. FTP-75 Cycle

The Original FTP-75 cycle was simulated as well as the modified cycle, the cycle with 2 and 5 sec look ahead kernels. The results of these simulations are shown in Table IV .The unrealistic increase in power needs of the modified cycle with no kernel can be seen, even though they are theoretically possible.

TABLE III. NEDC

Cycle	*Max power need (W)*		*End SOC (%)*	
Normal	41321		70.93	
Modified	46744	(+13.12 %)	70.67	(-0.37 %)
2 sec Kernel	45855	(+10.97 %)	70.78	(-0.21 %)

TABLE IV. FTP-75

Cycle	*Max power need (W)*		*End SOC (%)*	
Normal	36050		65.44	
Modified	70222	(+94.79 %)	62.20	(-4.95 %)
2 sec Kernel	42657	(+36.74 %)	63.66	(-2.72 %)
5 sec Kernel	35282	(-2.13 %)	65.49	(+0.08 %)

It can also be seen that the more experienced the driver is (represented by the increased kernel width), positive effects can occur such as reduced power needs and lower consumption (represented by the higher SOC at the end of the cycle).

C. WLTP

For the WLTP similar simulations were also made. We additionally had the opportunity to drive the cycle with an experienced driver that has already driven the cycle before and has also driven several other cycles. The test took place on our institute's acoustic roller test bench [9]. Because of the relative differences between our simulation model and the real vehicle as discussed in [7] and [8], the power needs and consumption were not taken directly as measurements from the vehicle. Instead, the actual speed profile during the tracking of the driving cycle was collected and then fed as input into the simulation model. The results of these simulations are shown in Table V.

TABLE V. WLTP

Cycle	*Max power need (W)*		*End SOC (%)*	
Normal	48074		59.42	
2 sec Kernel	65737	(+36.74 %)	57.79	(-2.74 %)
Real Driver	44266	(-7.92 %)	59.69	(+0.45 %)

VI. Conclusions

It has been proven that the driver's experience can have a great influence on the power needs and energy consumption during the tracking of driving cycles. These results may differentiate greatly from the given driving cycles power needs and consumption if it were to be driven autonomously. An unexperienced driver could lead up to 36.74 % more power need and 4.95% more consumption in the FTP-75 cycle. An experienced driver can in contrary have a positive effect where power needs are reduced by 2.13 % in the FTP-75 cycle and 7.92% in the WLTP cycle. A method to quantify these effects was introduced and tested on several standard test cycles.

The influence on energy consumption in the tests was not as drastic as the influence on power needs. This is due to the fact that all of the simulations were done without any active regenerative braking (which could lead to better energy consumption [7]). This means that the highest power peaks occurred during the acceleration phases. The presented method will later serve as a validation tool for the Regenerative Braking System under development as the deceleration phases will be of more interest [7]. This will be very useful while selecting the appropriate regenerative braking level.

References

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