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Developing a simple test method to compare the mileage of e-scooters

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Abstract

Following the trend in China, the fastest growth of electric vehicle fleets is seen for 2-wheelers i.e. bicycles, scooters and motorcycles. In Switzerland this development is supported by the national programme NewRide, an initiative of the SwissEnergy programme sponsored by the Swiss Federal Office of Energy. NewRide needs a method to compare energy consumption and driving range of e-scooters and e-motorcycles which is, however, not readily available. For that a project was designed to define a simple test method producing the required data. The experimental program was carried out with 3 different vehicles and consisted of test bench runs with the statutory cycle for Europe (New European Driving Cycle, NEDC) and one real-world cycle (World Motorbike Testing Cycle, WMTC) in order to determine the statutory and real-world performance of the e-scooter sample. The experiments revealed a number of issues and difficulties related to the use of a standard test bench for testing electric 2-wheelers. The results of the cycle tests are presented, the critical issues encountered are discussed and a simple test method using a test bench and a standard test cycle is suggested. A brief outlook on the next test series where the experiments on the test bench will be replaced by in situ road tests is given.

motorcycle, scooter, vehicle performance, RCS (Regulations Codes and Standards), standardization, simulation

1 Introduction

Recently electric vehicles (EV) attract worldwide much attention as they could offer a number of solutions to current and future problems related to road transportation. Consumers in Switzerland follow the trend in China, where the fastest growth of EV fleets is seen for 2-wheelers i.e. bicycles, scooters and motorcycles. This development is supported by the Swiss national programme NewRide, an initiative of the SwissEnergy programme sponsored by the Swiss Federal Office of Energy (FOEN).

NewRide supports the introduction of electric bicycles (e-bikes) as well as electric scooters and motorcycles (e-scooters) into the Swiss market. In close collaboration with municipalities and companies, as well as with a network of manufacturers, importers and dealers, this programme offers a range of communication and organisational services, for example road shows at which people have an opportunity to test drive e-2wheeler.

In the past years NewRide successfully helped to stimulate the sales of e-bikes (units sold: 13’000 (2008); 7'000 (2007); 1'000 (2002), [1]). For 2009 the programme will focus on the promotion of e-scooters and expects to have a similar success in increasing acceptance and sales. Important arguments for a consumers' purchase decision are reliable figures to compare performance and mileage. NewRide provides such information, however, it is not readily available for e-scooters. Therefore a method to compare the energy consumption and driving range of e-scooters is required. The research project "Reichweiten- und Verbrauchsmessung an e-Scooter nach zukünftigem WMTC Standard" (mileage- and energy consumption measurement for e-scooters using the WMTC standard), financed by Empa and FOEN, is designed to define a simple test method producing the required data.

The objectives of the project are:

- to find a method which is simple, low cost und general (i.e. uses existing chassis dynamometers, requires minimal el. measuring technology, …)
- Determine vehicle cycle on chassis dynamometers (kinematic & dynamic)
- Determine battery cycle dynamic on a stand alone test bench (voltage, capacity, ...)
- both aspects are arithmetically combined to determine performance & mileage.
- comparison of the results with life test runs
- develop a 'no bench' test based entirely on 'in situ' measurements.

This paper presents the test method and the results of the driving cycle tests and discusses the critical issues encountered. A brief outlook on the next test series where the experiments on the test bench will be replaced by in situ road tests is given.

2 Tests

Three rather divers e-scooters were selected for the driving cycle test (see Table 1) - due to that we expected to encounter a variety of issues. We decided to perform a number runs on the chassis dynamometer in Empa's motor lab (see Figure 2). We restricted the tests to the WMTC [2] cross-checking the results with the NEDC [3] (see also Chap 2.2).

1 2 3

Figure 1: 1) Quantya "Evo 1", 2) Oxygen "Postscooter", 3) Mobilec "Mobilec"

Table 1: eScooters specification and test cycle description

make [-]	model [-]	empty mass [kg]	battery capacity [kWh]	power [kW]	gearbox [-]	voltaje [V]	velocity v_max [km/h]	NEFZ class [-]	WMTC class [-]
Quantya	Evo-1 Strada	85	2	8.5	none	48	>70	part 1urban	1 reduced
Oxygen	Postscooter	178	4.8	3	none	48	45	part 1urban	1 reduced
Mobilec	Mobilec	90	0.9	0.8	none	24	30	part 1urban	1 reduced

2.1 Test Equipment

2.1.1 Chassis Dynamometer

The measurements on the chassis dynamometer were conducted according to the directive 97/24-2005/51/EG. The inertia and frictions were calculated and set for motorcycles according to the directive 97/24-2005/51/EG, Ann II, 1a. To the "empty mass" in Table 1 a 100kg driver was added.

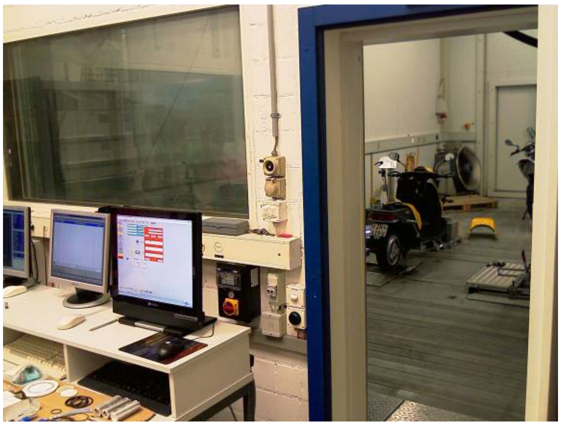

Figure 2: Chassis dynamometer at Empa.

2.1.2 Electric measurement

Electrical measurements were sampled, digitized, displayed and recorded with a LeCroy Waverunner 44XI using 8bit D/A-converter with adjustable sampling rates (we used 500-1000S/s). The battery current was converted by a DC current transducer (LEM HTFS 200-P) to a symmetric voltage of +/- 2.5V for the entire current range of +/- 300A_peak.
In addition, testing of electric (and hybrid) e-scooters will require the use of emissions measurement procedures. However, this was not part of this measurement campaign. The battery's voltage was measured directly without any signal conditioning.

2.1.3 Dataprocessing

Electrical energy and power as well as power factors and harmonics were calculated using Matlab. Also offsets (e.g. of the current transducer) were corrected and the signals were filtered via Matlab according to our needs.

2.1.4 Electronic load

In order to discharge the battery and derive the battery's effective ampere-hours we intended to use an electronic load. Our initial experiments showed, however, that the full integration of the battery management system with the e-scooter control system, does not allow to easily divert discharge current to an external sink. We abandoned this concept altogether.

2.2 Drive Cycles for e-Scooters

In order to test compliance with norms and measure energy consumption, well defined drive cycles are used. A selection of existing drive cycles have been analysed for their suitability for e-scooters [4].
The "real-world" cycles represent average driving behaviour. They are often subdivided in three sections: Urban, Extra-urban und Highway. The following three driving cycles were used in [5]

- CADC: the Common ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) Drive Cycle [6]
- WMTC: World-wide harmonized Motorcycle emission Test Cycle [2]
- FHB: Fachhochschule Biel Cycles (FHB: for motorcycles, SMSP: developed for 50ccm, <45km/h scooter, MES2: developed for scooter with no speed limit, ISB3 & ISB-HIWR: developed for motorcycles)

Table 2: Salient features of WMTC and NEDC

	part	time [s]	distance [m]		avg. speed [km/h]		max. acceleration [m/s2]		max. deceleration [m/s2]	
			normal	reduced	normal	reduced	normal	reduced	normal	reduced
WMTC	1 - urban	600	4'065	3'837	24.4	23.0	2.51	1.72	-2.00	-1.94
WMTC	2 - extra-urban	600	9'111	8'448	54.7	50.7	2.68	1.77	-2.02	-2.02
WMTC	3 - motorways	600	15'736	14'436	94.4	86.6	1.56	1.56	-2.00	-2.00
WMTC	total	1800	28'913	26'721	57.8	53.4	2.68	1.77	-2.02	-2.02
NEDC	urban	1170	6'088		18.7		1.04		-0.93	
NEDC	extra-urban	400	6'955		62.6		0.83		-1.39	
NEDC	total	1570	13'042		29.9		1.04		-1.39	

Table 3: WMTC classification and interpretation for eScooter

Vehicle		Class definition		Part 1 Urban street		Part 2 Country road		Part 3 Motorway	
class	subclass	combustion engines	electric engines	reduced 50 km/h	normal 60 km/h	reduced 82 km/h	normal 95 km/h	reduced 111 km/h	normal 125 km/h
1	-	vmax < 50 km/h; engine 50 .. 150 cm^3	vmax < 50 km/h	X					
	-	vmax 50 .. 100 km/h; engine < 150 cm^3	vmax = 50 .. 100 km/h	X					
2	2-1	vmax 100 ..115 km/h; engine < 150 cm^3 & vmax < 115 km/h; engine ≥150 cm^3	vmax = 100 .. 114 km/h	X		X			
	2-2	vmax 115 .. 130 km/h	vmax = 115 .. 129 km/h		X		X		
3	3-1	vmax 130 .. 140 km/h	vmax = 130 .. 139 km/h		X		X	X	
	3-2	vmax >= 140 km/h	vmax > 140 km/h		X		X		X

The "synthetic drive cycles" simplify the definition of speed by using only linear speed profiles. The following 3 drive cycles are discussed in [7] and originate from [2] [8]:

- ECE 40: (Economic Commission for Europe), urban driving cycle (UDC) for motorcyles.
- ECE 40m: same as ECE 40, but without initial 40s idling.
- ECE 47: urban driving cycle for mopeds
- NEDC+: adapted for motorcycles using 6 times UDCs and once an extra-urban part which, however, is left out for slower motorcycles.

The WMTC and the NEDC was used for testing the Evo1 and the Postscooter. The WMTC requires some interpretation in terms of classification of vehicles below 100km/h for which the allocation of WMTC cycle modules is a function of v_max and engine capacity (either class 1 or 2-1); According to Table 3 all tested vehicles belong to class 1 and are subject to the 'reduced' WMTC (see Table 1). A reduced NEDC (leaving out the extra-urban part) was used. For the Mobilec a "v_max driving cycle" adopted from [9]) was used (i.e. the fully charged battery is discharged at full speed until the battery management system interrupts the current for the first time).

The batteries where fully discharged after the drive cycle tests using a "v_max driving cycle" approach. Subsequently the batteries were fully charged using the regular charger and grid voltage and current were logged.

3 Results

The major results of the measurement campaign are summarized in Table 4.

- Quantya: the range is calculated with the established specific consumption and the battery capacity given by the producer.
- Oxygen: the required max. speed is not attained in either of the tests. The expected lack of covered distance is only apparent in the NEDC (-5%) and is minor thus the specific energy consumption is hardly affected.
- Mobilec: was not able to follow either of the two driving cycles. A "v_max driving cycle" was used to gather the results.
- The battery recharging was done for the Evo1 and the Mobilec and resulted in an energy demand of 2'305Wh and 703.6Wh respectively.

Table 4: Summary of tests

make [-]	test cycle	energy consumption [Wh]	covered distance [km]	spec. energy consumption [Wh/km]	consumtion petrol equiv. [liter/100km]	calculated range [km]
Quantya	NEDC	221	6.022 (6.088 -1.1%)	36.70	0.415	54
	WMTC	142	3.881 (3.837 +1.1%)	36.59	0.413	55
Oxygen	NEDC	171	5.796 (6.088 -4.8%)	29.50	0.333	163
	WMTC	112	3.868 (3.837 +0.8%)	28.96	0.327	166
Mobilec	-	450	21.667 (-)	20.77	0.235	43

The 80% charging time was 242.9min and 93.7min respectively.

4 Discussion

As expected a number of issues arose in setting up and conducting these tests:

- The chassis dynamometer needed some adopting and tuning due to the lightweight and softpower of the e-scooters. There still are some stability issues in controlling the velocity. We couldn't determine whether they are to be attributed to the dynamometer or e-scooter controller; or if it is their interaction.
- The need to rewire the e-scooter for measuring the electrical parameters is problematic as the wiring / battery connectors are often not accessible and there results a substantial risk in short circuiting and damaging the electrical equipment. Some precaution may be taken e.g. the current transducers must be of split-core type.
- The attempt to use an electronic load to discharge the battery proved to be too risky. There is not adequate information available on how to interfere with the wiring.
  To do a full discharge with WMTC urban cycles takes a considerable amount of time which increases test costs. On the other hand to use a "v_max" discharge often makes the battery management system (BMS) intervene before the full capacity is used. For the Evo1 for instance only 36Ah of the available 40Ah were available!
- Both driving cycles, WMTC and NEDC, are too demanding for low powered e-scooters (<2.5-3kW). They can cope neither with the acceleration nor with the max. speed. However, in calculating the specific energy consumption, this seems not to show up and a (calculated) compensation can be left out [9] but indicating the 'Fehlzeit' the time during which the e-scooter can't follow the driving cycle. Nevertheless this approach seems problematic at higher speeds where nonlinear friction losses start to dominate.

5 Outlook

In order to reduce the complexity of infrastructure requirements and the rigid regime of defined drive cycle tests we plan to extend the test method to an in-situ setup. The vehicle's kinematic and dynamic will partly be measured with appropriate onboard equipment (position (via GPS), 3d acceleration, relevant voltage- and current measurement, etc.) and partly calculated numerical via a 'grey box model' approach. The vehicle will be characterised

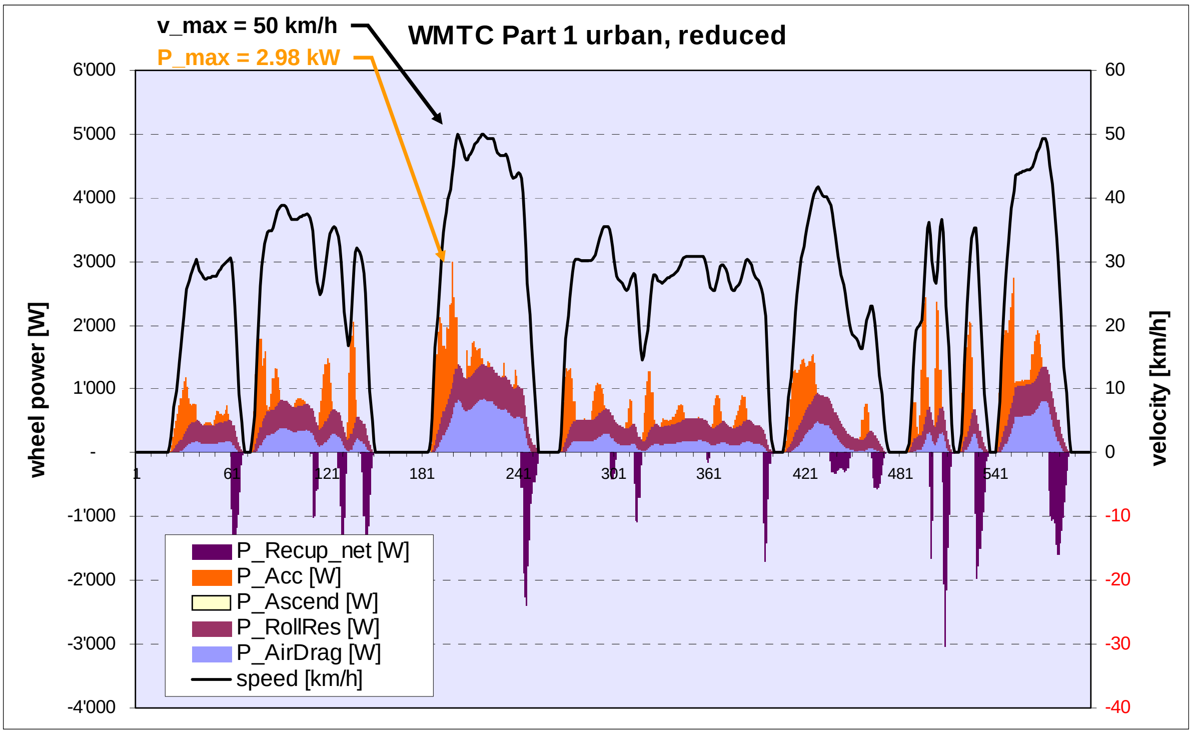

Figure 3: power consumption of a model e-scooter subjected to a reduced WMTC. The different energy uses accumulate and are indicated in different colours: P_Recup_net is the net recuperated power and are seen as the negative spikes during decelerations; P_Acc, P_Ascend, P_RollRes and P_AirDrag is the power required for an Accelaration, climbing, and friction to ground and air respectively.

with a adequate model and its parameters will be identified from the acquired in-situ driving data. Once the parameters are known any driving cycle performance can hopefully be calculated within acceptable tolerances using the model.
Figure 1 displays a power simulation for an e-scooter model running a 'reduced part1' WMTC.
The characteristics are:

weight vehicle:	120 kg
weight driver:	80 kg
projection area:	0.75 m2
air drag coefficient:	0.7
rolling resistance:	0.02

The reduced part 1WMTC has

speed (v_max)	50 km/h
acceleration (a_max)	1.72 m/s2
distance (10 min):	3037 m

and requires from the model e-scooter

power (wheel):	2.98kW
energy (100km):	2.90kWh

(equals constant 52km/h)

Acknowledgments

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