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Research Article

ANALYSIS OF TROLLEYBUS ENERGY CONSUMPTION

Ewa Siemionek[1]

[1] Department of Automotive Vehicles, Faculty of Mechanical Engineering, Lublin University of Technology, 36 Nadbystrzycka Str., 20-618 Lublin, Poland, e-mail: e.siemionek@pollub.pl

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ABSTRACT
Developing energy-saving solutions in vehicle construction and operation has become a priority in the automotive sector. For this reason, zero-emission and low-noise trolleybuses have started to play a significant role in urban public transportation. The paper discusses the methodology and results of energy consumption analysis for trolleybus travel on a determined route. For a given section of the route, energy recovery under braking was calculated.

Keywords: energy consumption, trolleybuses.

INTRODUCTION

Public transportation is globally undergoing a series of reforms aimed at the reduction of environmental pollution and noise caused by various means of transport. From an ecological standpoint, it is favorable to launch successively the vehicles with electric drive in the market, and presently, renewed interest in such vehicles can be observed due to the technological progress in the production of electric energy from renewable sources. In recent years, power engineering problems have become the most important aspect of transportation development policies and the selection of transport means. Therefore, zero-emission vehicles, such as trolleybuses, have acquired particular significance in this respect.

There have been actions undertaken to reduce exhaust emissions and energy consumption used to meet the transport needs of the Lublin region. In order to calculate the energy balance for the public transportation in Lublin, trolleybus energy consumption in real operating conditions was investigated [2, 3, 4].

TEST OBJECT CHARACTERISTICS

The first trolleybuses were built in Germany at the end of the 19th century. The name ”trolleybus” is a combination of two words: “trolley” (a pulley or truck travelling on an overhead track) and “bus” (from the Latin word “omnibus” meaning “for all”). A trolleybus is a road vehicle that is driven by electric energy supplied from an external source. Its motion is, to a large extent, dependent on electric traction system. In Poland, trolleybuses are usually powered by a direct current of approximately 600 V. The main advantages of these vehicles include: zero emissions, silent-running, high performance and overload capacity, shock elimination as well as a long operating time. The disadvantage of a trolleybus is the dependence of its routing on the electric traction supplying power to this vehicle.

Trolleybuses can be powered by different types of electric motors and control systems, from direct-current motors (series and compound ones) to alternating-current motors. Nowadays, all newly produced trolleybuses are equipped with a kinetic energy recovery system for recovering kinetic energy under braking. In the areas with high-density housing and low driving speed, trolleybuses with battery-powered traction motors are used, while on long straight sections of routes these vehicles draw power from overhead traction wiring.

EXPERIMENTAL DETAILS AND RESULTS

Experimental tests were conducted to determine energy consumption of trolleybuses. The test object was a Solaris Trollino 12 AC (Figure 1). Table 1 lists basic technical data of the vehicle.

The following values were measured:

- supply voltage,
- current strength drawn from the traction by the motor and control system,
- vehicle speed,
- acceleration and time delay,
- energy consumption for the designated route.

During the measurements, geographic coordinates were recorded.

Fig. 1. Tested vehicle – Solaris Trollino 12

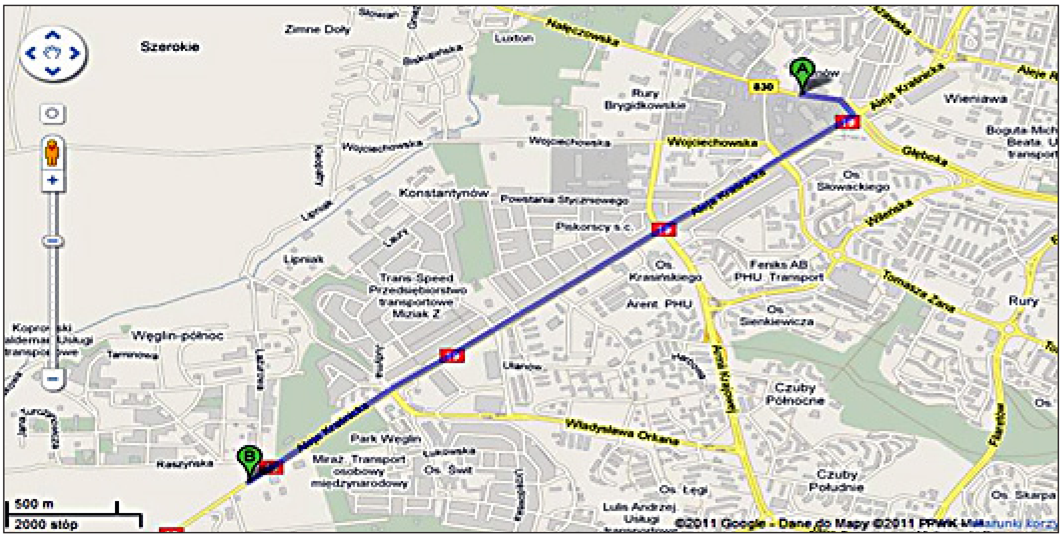

Fig. 2. Route traveled by the trolleybus

Table 1. Technical date of Trolleybus

Solaris Trollino 12 – Technical Data	
Length/Width/Height	12000 / 2550 / 3135 – 3490* [mm]
Interior Height	2370 [mm]
Front Overhang /Rear Overhang	2700/3400 [mm]
Angle of Approach/Departure	7/7 degrees
Curb Weight / Gross Vehicle Weight	11 600 – 14 100 / 18 000 [kg]
Wheelbase	5900 [mm]
Turning circle	~21,4 [m]
Motor	4-pole asynchronous motor (Škoda 4ML3444 K/4 160 kW)
Control System	TV Europulse (IGBT) CEGELEC ANT 175-600 (IGBT) MEDCOM Škoda BlueDrive (IGBT)

The route (Figure 2) was determined by the AB-BA section with a length of 7.2 km. The tested vehicle was in good working order. At vehicle running, all roof vents and windows were closed. The devices necessary for safe vehicle operation were switched on, while others were off. The working temperature of particular units had a steady value owing to the preliminary test run. During the tests, changes in voltage, current strength, vehicle speed (Figure 3) and acceleration as a function of time were measured [9].

As the time history for traction voltage demonstrates, a sudden voltage drop occurred in the 520th section, caused by sudden vehicle braking. As a result, voltage supply lines were disconnected. Higher voltage variations occurred when the vehicle was at a longer distance from the substation supplying power to the contact system. The energy was recovered under brak-

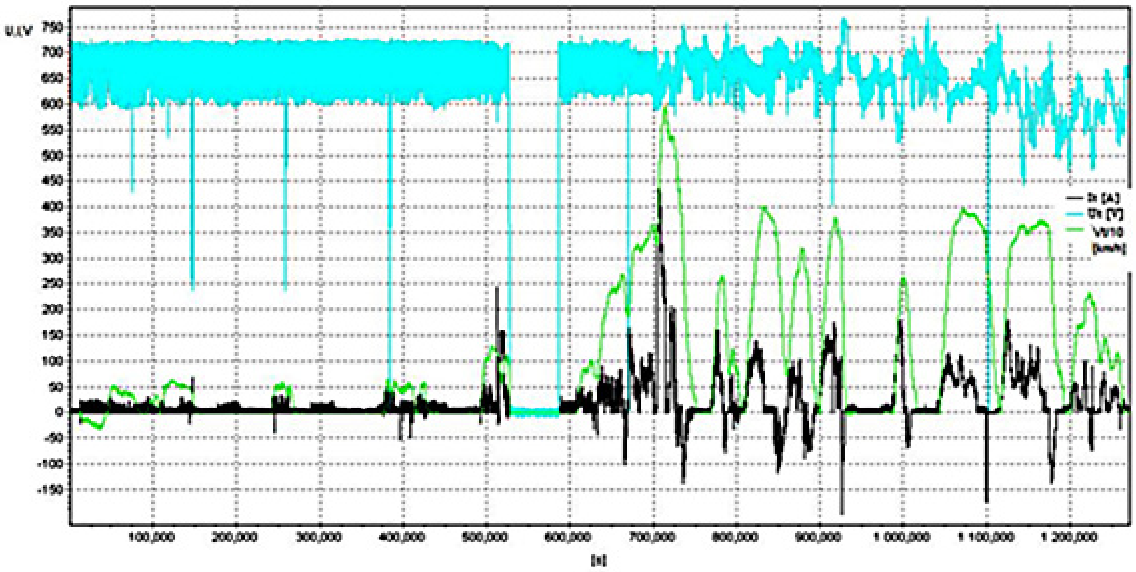

Fig. 3. Voltage, current strength and vehicle speed as a function of time

Table 2. Comparison of data, energy consumption results and kinematic parameters for section AB

Parameter	1	2	3	4	5	6	7	8
L_c [m]	410.76	708.453	581.45	209.44	132.97	580.26	731.37	270.48
T_c [s]	66	70	89	36	52	80	69	80
V_c [m²/s²]	16.28	13.4	20.069	10.85	12.67	19.75	22.82	8.38
T_a [s]	23	30	36	13	15	28	18	26
T_u [s]	5	E	3	1	0	12	16	5
T_z [s]	14	21	17	8	4	13	20	13
L_z [m]	143,3	280.83	204.44	87.5	36.38	151.11	237.77	50.5
L_n [m]	338.13	679.37	500.82	176.5	98	504.71	237.77	50.55
L_h [m]	72.63	29.083	80.63	32.94	34.97	75.55	48.61	75.3
T_h [s]	18	8	19	10	10	18	13	28
L^*	0.823181	0.958949	0.861329	0.842723	0.737008	0.8698	0.325102	0.18689
V^* [m²/s²]	13.40139	12.84991	17.28602	9.143549	9.337896	17.17854	7.418832	1.566138
a^* [m/s²]	0.198169	0.094572	0.172577	0.259024	0.476423	0.170182	0.156009	0.15491
E_t [J]	437851.3	879729.8	648521.8	228553.4	126902.2	653559.1	307893.1	65458.21
E_p [J]	17064.74	28221.03	31157.97	5936.578	3849.146	30900.87	16820.33	1313.188
E_k [J]	976800	804000	1204140	651000	760200	1185000	1369200	502800
E [J]	1431716	1711951	1883820	885490	890951.3	1869460	1693913	569571.4
E_t / E	0.305823	0.513876	0.344259	0.25811	0.142434	0.349598	0.181764	0.114925
E_p / E	0.011919	0.016485	0.01654	0.006704	0.00432	0.016529	0.00993	0.002306
E_k / E	0.682258	0.46964	0.639201	0.735185	0.853245	0.633873	0.806306	0.882769
ψ	3435.529	2416.464	3239.866	4227.893	6700.393	3221.763	2316.083	2105.78
Φ	0.290461	0.201372	0.269989	0.352324	0.558366	0.26848	0.193007	0.175482

ing, which is demonstrated by the negative values of current strength as a function of time. The highest energy recovery occurred at frequent changes in speed profiles.

Based on the technical data and recorded changes in voltage, current strength, vehicle speed and acceleration values, selected traction parameters were calculated.

The following data were determined: total distance covered, total time, mean speed, drive time, time of steady motion, slow-down time, as well as energy balance elements between particular stops on the route. Table 2 shows an example of the comparison made for the data and calculation results.

CONCLUSIONS

Analyzing the available studies, it can be observed that one of the basic criteria for the evaluation of public transportation involves operating costs, which depend on energy consumption in real operating conditions[1, 5, 6, 7, 8].

Based on the results obtained, it has been found that energy consumption level is the same for a particular route if the operating conditions are maintained the same.

The energy balance for the tested object demonstrates that energy consumption of the trolleybus on the traveled route section was 5 kWh. The energy recovered on the designated section of the route was approximately 20% of the total energy.

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