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Importance of real operating parameters for design of public transport vehicles drive

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Abstract

One of the most frequent topics of professional community is the ecology of transport. Different types of transport need individual approach to design suitable drive of vehicles. At design of public transport vehicles drives it is important to work with parameters close to the real conditions of using the drive or with real measured parameters. It helps to find the best conception of the drive and so reduce the consumptions of energy and the production of air pollutants. Energy intensity of the vehicle is usually determined on the basis of a driving simulation based on driving cycles for fuel consumption and harmful emissions measuring. These driving cycles are simplified and do not include the grading resistance, therefore, they are insufficient to determine certain specific conditions. Compilation of driving simulation based on real driving cycles measured during the vehicle driving in urban traffic seems to be more appropriate for specific vehicles, such as buses for public transport are. The aim of this paper is to show to what extent the use of standard driving cycles for the design of electric drives, respectively hybrid drives of vehicles, is consistent with real conditions.

Introduction

High efficiency, low level of the noise and harmful emissions are essential requirements imposed on public transport vehicles. These requirements can not be successfully provide only by conventional drives with internal combustion engines and thus the importance of the use of electric and hybrid vehicles in public transport increase.

The importance of hybrid and electric vehicles in the field of city public transport means is still increasing. In order to properly design the drives of these vehicles, their application and the real possibility of their use in the operation has to be obvious. Efficiency of utilization of these drive systems depends on their right combination and dimensioning [1, 2].

Because of the need to reduce the vehicle energy consumption and emissions some systems for the accumulation of kinetic energy from braking, which would be otherwise wasted by heat as well as systems which switch off the combustion engine, while vehicle standing as stop/start system are currently designed [3]. Proposals similar devices as well as the hybrids are usually based on driving cycles for determining of fuel consumption and harmful emissions as for example, Millbrook Westminster London Bus cycle – inner London, Braunschweig bus cycle or BP bus cycle [4].

However, these cycles don't contain the grade resistance or real progress of braking deceleration and are simplified. In contrast, in normal traffic, there is often slow down, respectively a short-term braking which can be only a minor source of recovered energy [5].

Driving cycles timing

The right timing of the real driving cycles measurement is very important. As stated in [6] there are big differences in the traffic during the day and during the week too.

The chart on the figure 1 shows how the number of trips in progress changes over the course of 24 hours for different days of the week. The chart is presented as an index which compares the number of trips in progress per hour on a weekday, a Saturday and a Sunday with the average number of trips in progress per hour across all hours in a week.

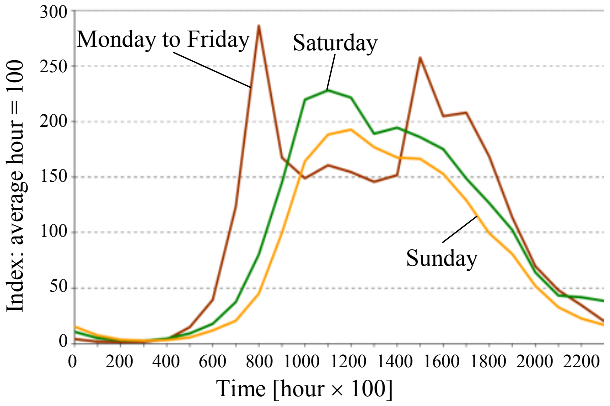

Fig. 1. Trips in progress by time of day and day of week – index: Great Britain, 2012 [6]

The chart shows two peak hours for the number of trips in progress on a weekday (Monday to Friday). The first (and highest peak) is in the morning between 8:00 and 8:59 when there are nearly three times as many trips in progress when compared with the average hour. The second peak is in the afternoon between 15:00 and 15:59. Both peaks are driven by education related trips. There is only one peak hour for trips in progress at the weekend. On Saturday the peak hour is between 11:00 and 11:59 and on Sunday the peak hour is between 12:00 and 12:59. Overall the number of trips in progress on a Sunday is 24% lower when compared with the average day.

On the average weekday, the majority of trips starting between 01:00 and 07:59 were for commuting purposes and again between 16:00 and 17:59. From 18:00 until 00:59, the majority of trips are for visiting friends, entertainment and sport purposes. 36% of shopping trips start between 10:00 and 12:59. 40% of education trips start between 08:00 and 08:59 and 32% start between 15:00 and 15:59.

Business trips are more evenly distributed throughout the daytime, as are personal business trips (such as visiting the doctor, hairdresser or a library) and holiday/day trips.

The busiest day of the week in terms of the number of trips was Friday with 150 trips per capita per year. On average, more commuting trips take place on weekdays than the weekend but a small variation exists between weekdays. On Tuesday, Wednesday and Thursday there are an average of 28 commuting trips per capita per year, compared with 26 trips on Monday and Friday.

Saturday is the most popular day for shopping and sport or entertainment trips with an average of 42 and 12 trips per capita per year, respectively.

The average number of trips varies across different months of the year according to trip purpose. Patterns of work, education and holiday trips reflect the influence of school and other holidays. In 2008/12, on average, more trips take place in March than any other month with 85 trips per capita per year. December had the fewest number of trips with 74 trips per capita per year.

Corresponding with the school holidays in August, trips for education purposes are very low and the number of trips made for holidays or day trips peaks.

Based on these facts and because it is assumed that electric and hybrid vehicles will be used mostly for transportation to job and shopping by their owners, the measurements were performed in real time of their use, in the time of afternoon rush hours from 14:00 to 16:30 hrs. This time, typical for our region, is characterized by growing number of traffic congestions and longer standing at intersections. The most energy-demanding regimes of frequent acceleration and braking were recorded by this way.

Measurement of real driving cycles

For the purpose of comparison of standardized and real driving cycles several measurements of real driving cycles in different cities of Poland, Czech Republic and Slovakia were performed. Speed, distance, acceleration, breaking point and elevation were measured. The measuring equipment consisting of measuring unit DAS 3 with contactless speed sensor, GPS receiver NaviLock NL-302U and CORRSYS-DATRON Pedal Force Sensor (Fig. 2) were used for collecting of the data on vehicle movement.

Fig. 2. Measuring equipment

Table 1 shows the basic characteristic parameters of driving cycles measured in bus lines of the public transport in Zilina.

Figure 3 represent the course of the line route 27 and the elevation profile in figure 4. Results of driving cycles analysis shown the relatively big

Table 1. Characteristic parameters of real driving cycles of city transport bus lines in Žilina

Bus line	Distance	Average speed	Time of cycle	Max. descent	Max. ascent	Aver. ascent	Aver. descent
	[km]	[km·h^{-1}]	[min]	[%]	[%]	[%]	[%]
Line 21	8.9	22.19	24	–16.9	12.6	1.3	–1.3
Line 27	15.5	29.96	31	–10.6	15.4	3.3	–2.3
Line 31	13.7	26.43	31	–15.2	10.0	1.7	–2.3

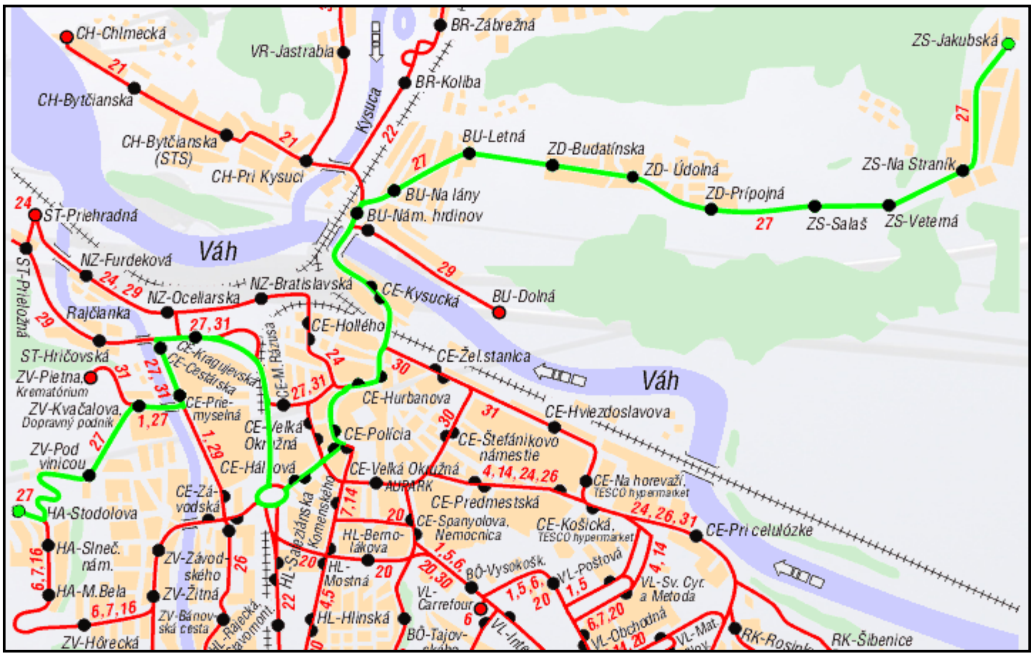

Fig. 3. Line route 27

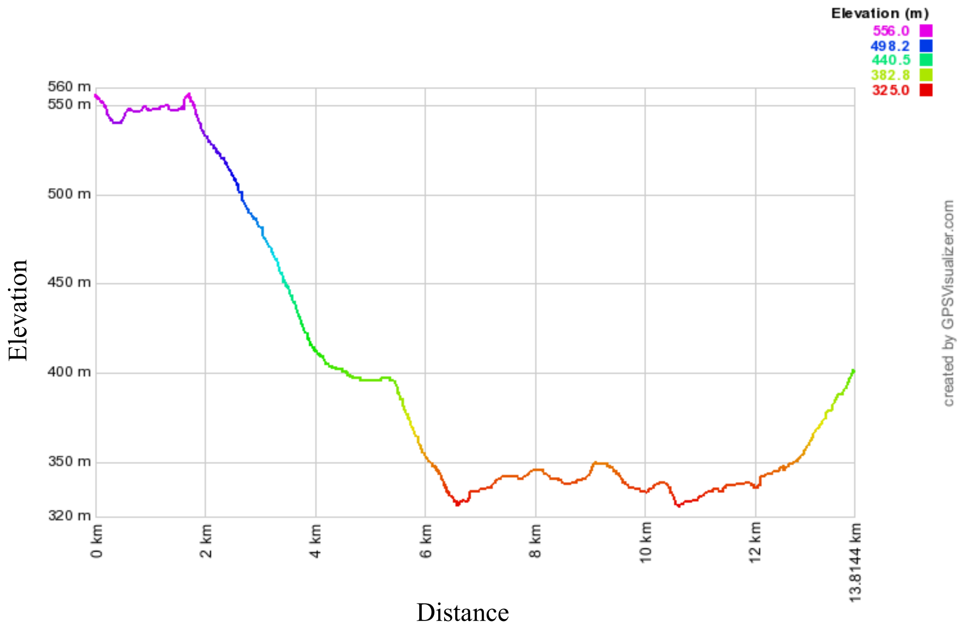

Fig. 4. Elevation profile of the bus line 27 – back

height differences in elevation profiles. However, the significantly differences in this values can be also between individual lines within the city.

Analysis of the standing time useful for the stop / start system design is shown in the table 2.

Table 2. Percentage of standing time in the real cycle

Line	21	21 back	27	27 back	31	31 back	Bus cycle
Standing [%]	15.3	18.5	11.2	12.2	19.4	16.9	16.55

The course of real driving cycle of the bus line 27 is shown in figure 5. The real driving cycles of specific bus lines were measured in both directions, back and forth, to ensure the objectivity of measurements.

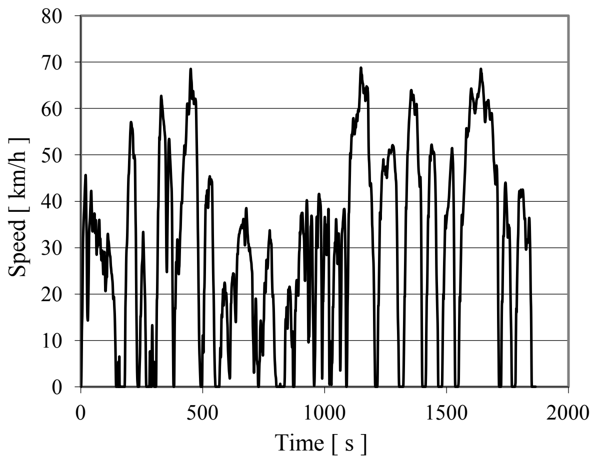

Fig. 5. Real driving cycle of the line 27

Simulation of hybrid bus drive

Serial hybrid drive of a bus was simulated in Matlab Simulink. Measured actual driving cycles were used as an input to the simulation. Required power of the bus was calculated based on the real driving cycle and selected parameters.

The simulation was done for 3 categories of buses (minibus, 10 m long bus and 12 m long bus) with specific parameters for different occupancy 25, 50, 100%. Four variants of serial hybrid drive with different parameters of key components were simulated. Two types of internal combustion engines with different power, two types of Li-ion batteries with different capacity, electric traction motor and two types of generators were used [7]. Based on the control strategy behavior of individual components of the hybrid system was simulated. Internal combustion engine operated in one revolution mode with the best specific fuel consumption. The operation of combustion engine was controlled by state of charge (SOC). If the SOC reaches preset lower limit combustion engine was turned on. When SOC reaches preset top limit where the battery was fully charged engine was turned off [8, 9].

The results of simulations based on the values from real measured driving cycles are shown on next figures. The energy E and average power P_{aver} required to pass the cycle and recoverable energy from the driving cycle E_{rek} were analysed.

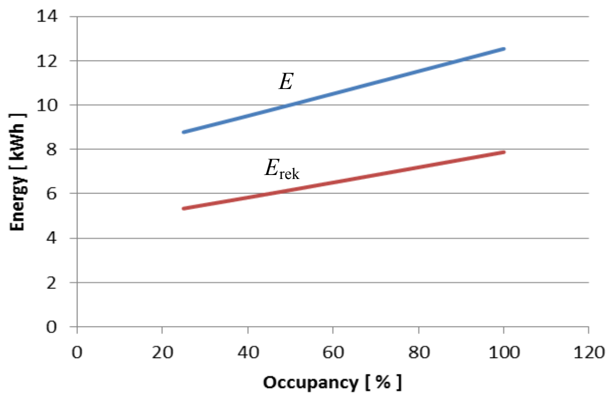

Fig. 6. Course of energies – Line 21 there

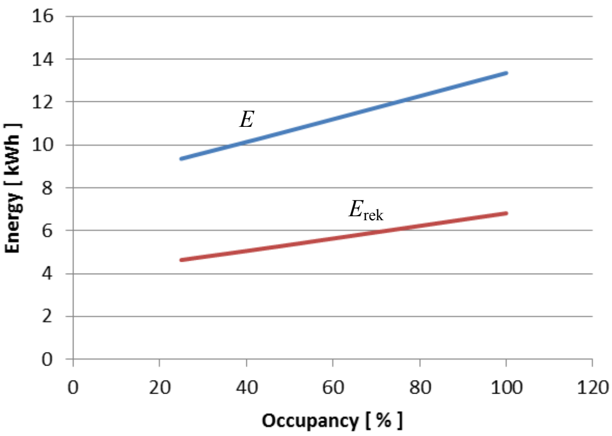

Fig. 7. Course of energies – Line 21 back

As can be seen from figures 6 and 7, the value of recoverable energy E_{rek} and energy required to pass the cycle E increase with the occupancy of the vehicle. There are some differences between values obtained at measurement in the direction back and forth caused by changes in the number of descents and climbs on the route (see elevation profile on figure 4). This fact leads to the need to take into account the measured values from both directions of the bus line route, when design the bus drive.

The figure 8 shows, that the maximum difference in the average power values at comparison with all three lines in both directions represent for example, at the 12 m long bus with the weight of 12 855 kg up to 25 kW, comparing the lines 21 and 27. This value represents 78% of the average power needed for the passing the line 21.

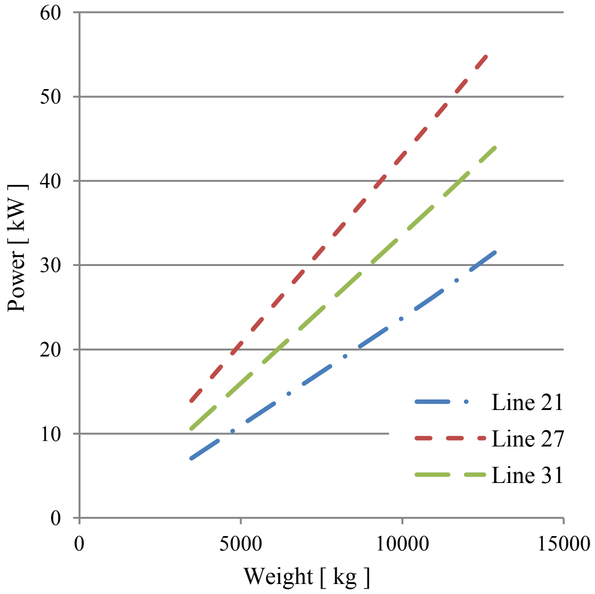

Fig. 8. Course of average power depend on the bus mass – 50% occupation

The figures 9 and 10 represent the course of the energy, which could be re-used from the driving. It can be seen that the amount of recoverable energy depends on the profile of the bus line route and can be very similar for some city lines (line 27 and 31 in the figure 10) but can be also very different for some line (line 21 in the figure 10). The same is with the energetic requirements on the buses. In one city the energetic requirements on the bus drives can be very diverse. These results point to the need of individual approach to the proposal of hybrid buses drives for each bus line. The figure 11 shows the trend of influencing the energy E required to pass the cycle depend on the bus mass.

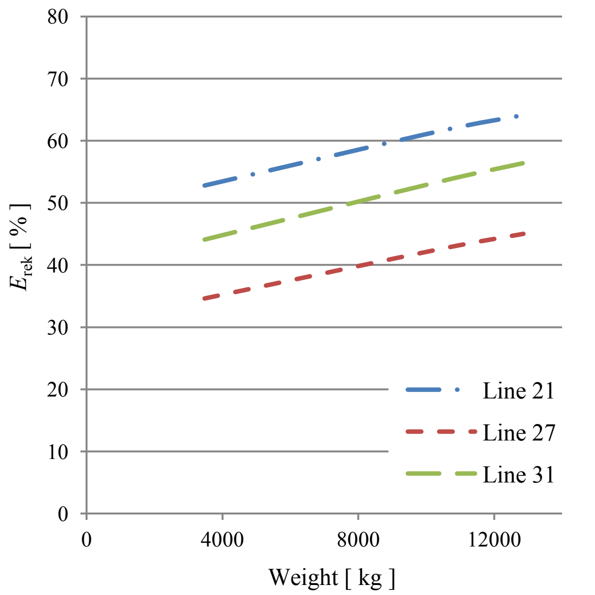

Fig. 9. Course of percentage of recoverable energy – 50% occupation

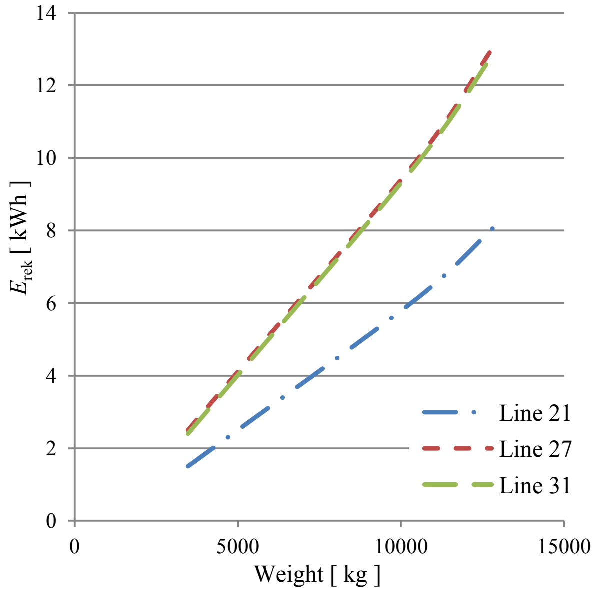

Fig. 10. Course of recoverable energy – 50% occupation

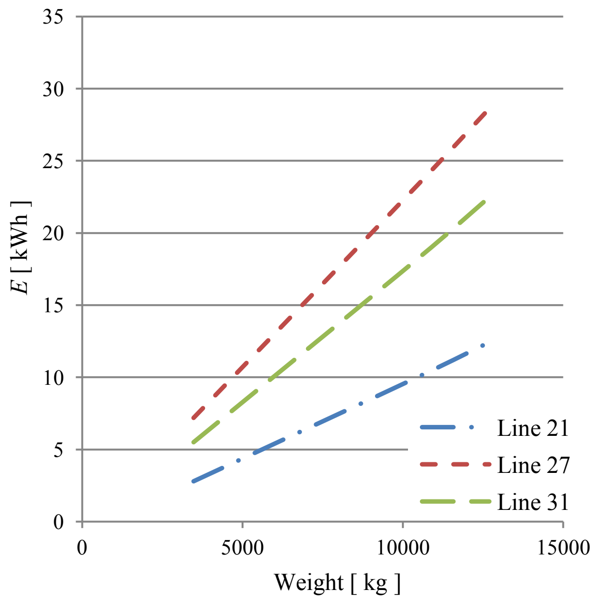

Fig. 11. Course of the energy required to pass the cycle E – 50% occupation

Conclusion

Correct design of a hybrid or electric drive depends on the appropriate choice and arrangement of individual elements in terms of their size, performance and capacity. Driving cycles measured in real traffic capture specific driving conditions of the city, respectively specific line characterized by the number of starts and stops, grade or driving speed and better characterize the real situation of the traffic in the city. Impact of the organization and the management the traffic in the city greatly affects the ratio of the time of standing and driving.

The concept of design of a modular hybrid drive with adaptive management has its justification in the design of urban buses, because it allows complete individualization of buses with hybrid drive with an emphasis on ensuring minimum impact on the environment and reducing of economic costs.

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