ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2495

IMPACT OF THE DRIVER BEHAVIOUR ON THE ENERGY RECUPERATION IN AN ELECTRIC VEHICLE

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Abstract

In recent years, energy recuperation systems have been used more and more often. This is due to the rapid development of electric and hybrid cars. In view of the growing technology that allows for a recuperation system efficiency increase, it is important to consider whether the weakest link is in this case not the driver and his ability to customize the driving style to the needs of energy recovery. This article attempts to answer this question. For that purpose, the special road tests were conducted in a real urban traffic. Two drivers were involved, each of whom used alternating recovery and non-recovery driving style. In total twelve road tests, realisations have been completed. The results of the measurements were entered into a mathematical model that simulated the work of the energy recuperation system. It allowed estimating how different recovery systems can work in the conditions of conducted tests. On this basis, an analysis was made both in terms of the total amount of energy that can be recovered in the case of recuperative and non-recuperative driving, and analysis of the recuperation system working and the real impact of the driver's driving style on the energy stored in the car's battery. Basis on the conducted considerations authors noted that use of recuperative driving technique could increase the amount of stored braking energy on average by 60%. It was also seen a significant impact on the energy waveform in the battery.

Keywords: *energy recuperation, driver behaviour, braking energy, mathematical model*

1. Introduction

The idea of recuperating energy in cars is to convert the braking energy into electrical energy, its storage and re-use to drive the vehicle or to power equipment installed on board. It is well known to use such a system in hybrid and electric vehicles. For several years, more and more energy recuperation systems have also occurred in combustion cars. There the energy recovered by the alternator is not used to drive the vehicle, but to power the car's current receivers [6, 7].

In the case of electric cars, braking energy recovery is the easiest to implement and most effective at the same time. This is because the same device is used simultaneously to drive the vehicle and to convert the braking energy to electricity. In addition, electric vehicles are equipped with high capacity batteries and relatively high charging power. In view of the growing technology that allows for the recuperation system efficiency improvement, it is worth considering if the weakest link in this case is not the driver and his ability to customize the driving style to the needs of energy recovery [2, 8].

To answer the question the road tests have been completed which registered the way of driving by different drivers. The results of the measurement were entered into the mathematical model simulating the work of the energy recovery system. On this basis, it was possible to assess how different driving techniques affect the real amount of recovered energy. The second chapter describes the theoretical foundations of the energy recuperation model and the calculation method. The third chapter presents the conducted research and their results from the model application.

2. Mathematical model of energy recuperation system

A computational model has been developed showing how the braking energy passes from the car's wheels, via energy converters, up to current receiver. The important thing is that not all the energy can be subjected to the process of recovery. Some of the kinetic energy is absorbed by the motion resistance, it mean rolling resistance and air resistance, and some part by the use of a brake by the driver. In brakes, energy is converted to heat and dissipated. Therefore, only 40% of the energy gets to the generator. Then the electric energy is transferred to the capacitor and finally it gets to the accumulator [3].

Brake energy is this part of kinetic energy, which has to be taken out from the vehicle to reduce its speed. In case of braking leading to stop the car the braking energy is the total kinetic energy of the vehicle that the car had before start of the braking process [9]. Figure 1 shows the kinetic power waveform to be inserted or withdrawn from the car to change its speed. It is set with the driving speed waveform. Positive value of power is associated with acceleration and negative with braking.

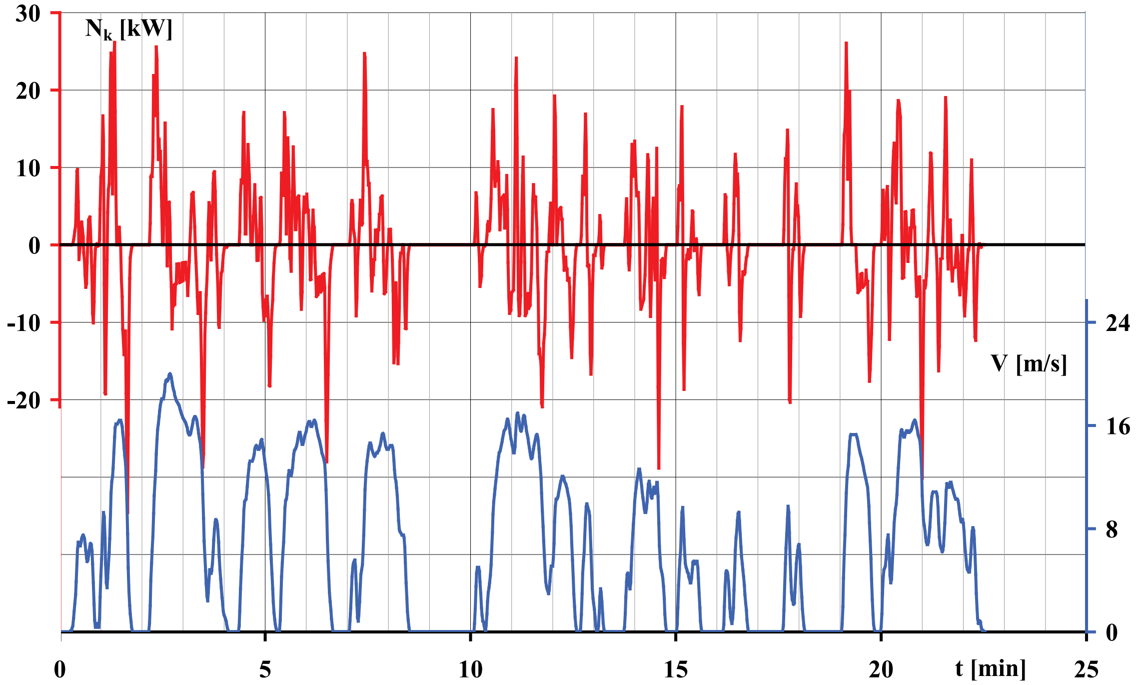

Fig. 1. The kinetic power (red line) and driving speed waveform (blue line)

The next element of the model is the inclusion of motion resistance that reduce the available kinetic power [1, 4]. It is worth comparing the sum of braking power with the resistance power (Fig. 2). Motion resistance will lead to reduced vehicle speed and thus will be part of the braking power reduce the power available to recover. The blue line represents the power that theoretically could be recovered from braking (excluding resistance losses) and red line – resistances power. Visually, this part of the braking power, which is above the power of resistance, can be recuperated.

The model should also take into account the use of the brakes by the driver. Now when the driver presses the brake pedal, the recovery process is given up. In this way, another part of the braking energy is lost [5, 9]. How much energy can be lost by that means and how much of it depends on the driver skills? This will be shown in detail in the third chapter.

Another element of the model is the generator. In the generator, we have two types of losses: associated with limited efficiency and associated with limited power. Much more important are the losses related to the limited power of the generator [3]. Wherever the braking power exceeds the power of the generator, the excess of energy is lost.

The destination site to energy storage is a chemical accumulator. However, the limitation in this case is the battery charging current. Therefore, an additional electrical energy buffer is used in form of a condenser or condenser assembly. Braking power is not distributed evenly over time but it is in the form of cyclic energy portions. Therefore, the current goes from the generator to the capacitor and it is passed to the receivers. If there is a surplus current in the capacitor then from the capacitor the current is transmitted additionally to the battery. Otherwise, the capacitor draws current from the battery to power the receivers [7].

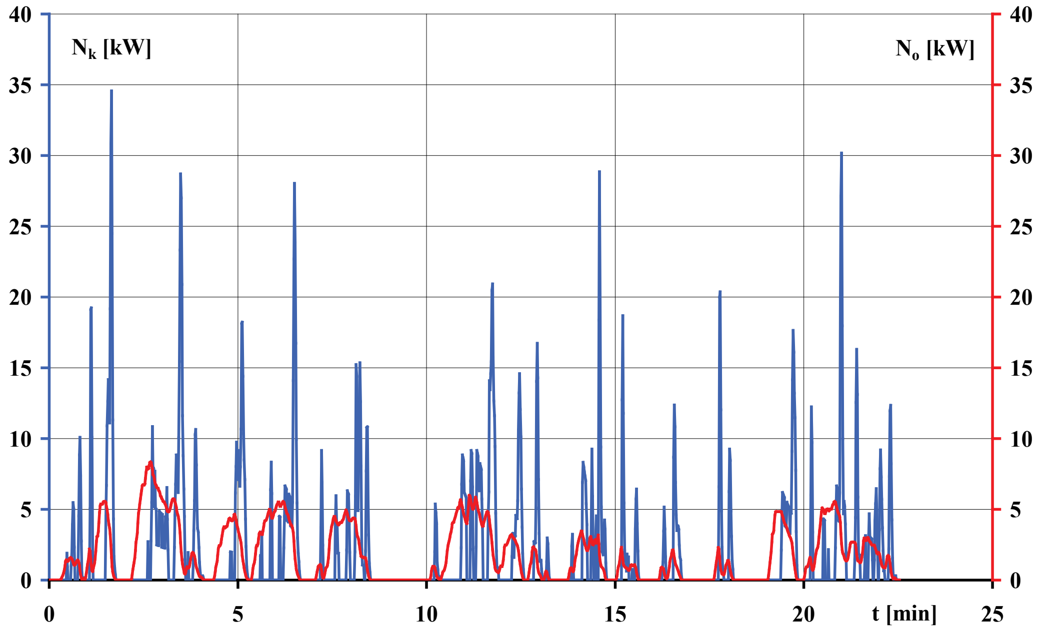

Fig. 2. The kinetic power waveform (blue line) and motion resistance power waveform (red line)

Fig. 3 shows the course of energy stored in the capacitor, which is juxtaposed with driving speed waveform. In places where an increase of energy in the capacitor is visible, the braking process occurred and the energy was recovered. However, in places where a decrease in energy is visible the recuperation process did not occur. If a temporarily stored braking energy exceeds, the possibility of its accommodation by the capacitor, excess energy is lost.

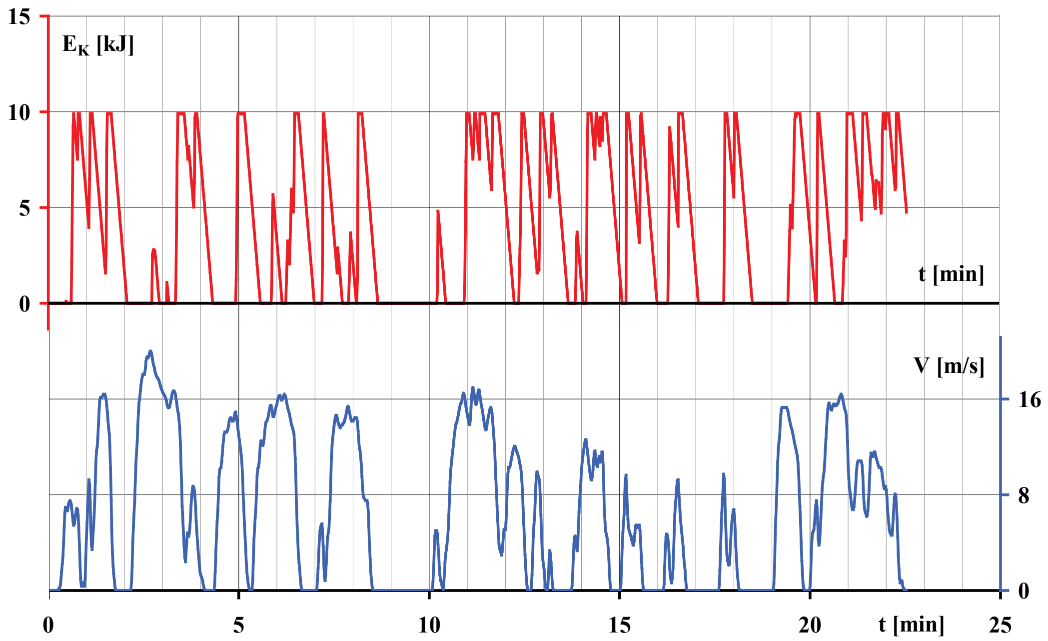

Fig. 3. The energy stored in the capacitor waveform (red line) and driving speed waveform (blue line)

The last link in the process of recuperating energy is its storage in a chemical battery. In this case, there are two limitations. The first is the efficiency of the battery and the second one is low charging power [6]. Fig. 4 shows the waveform of an energy stored in the battery combined with the driving speed waveform. The graph shows more or less constant power level in the battery with a relatively small downward trend. It should be emphasized that for the purposes of these calculations it was adopted that 100% of the energy supplied to the battery comes only from the energy recovery process, clearly to illustrate the problem of the amount of energy deriving from the recuperation system. This makes it possible to assess the energy balance in the battery.

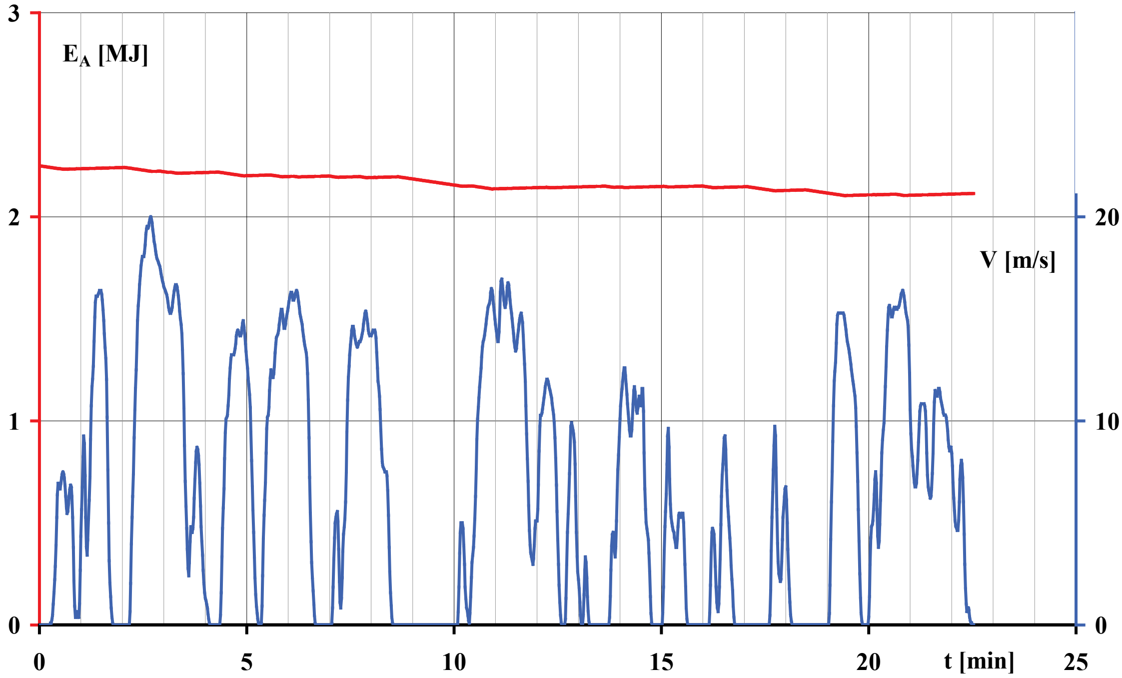

Fig. 4. The energy stored in the battery waveform (red line) and driving speed waveform (blue line)

3. Road test results

Car to the study was the Citroen C4 Picasso from 2014 years, with spark ignition engine, with a power of 88 kW/3500 rpm. Measured physical quantities were driving speed and engine speed. For measuring on-board car sensors was used and for registration OBD interface CarChip Pro that measured the driving speed to 1 km/h and engine speed to 1 rpm. The sampling frequency was 1 Hz. The research was conducted in real urban traffic on a fixed route with a length of 8.9 km. The study covered 12 journeys along the route with different driver configurations. All measurements were made one day, between 10:00 and 15:00. Driving style was adapted into a cars stream on the road. The average journey time was 19 min, average driving speed: 28 km/h, and maximum driving speed: 80 km/h. Two drivers were involved in the study, each of which used alternating recovery and non-recovery driving style, so there were four total types of rides. Each of these four types of rides was repeated three times; hence, the total number of test realization was twelve.

The key element of the results analysis was the energy recovery or the lack of recovery, depending on the braking method. If the driver brakes with recuperation, the speed decreases gradually along with a drop in driving speed. Otherwise, the speed dropped sharply before starting the braking process and remained close to the minimum value. Figures 5 and 6 show the examples of engine speed combined with the driving speed. The first of the graphs (Fig. 5) represents the recovery braking and the second one (Fig. 6) non-recovery braking. In the second graph, the situation when the engine speed is remained around the minimum value during the braking process is seen relatively often. This means that the clutch pedal was pressed at that time or the neutral was switched so the vehicle wheels were not connected to the car's drive and the recuperation process was impossible.

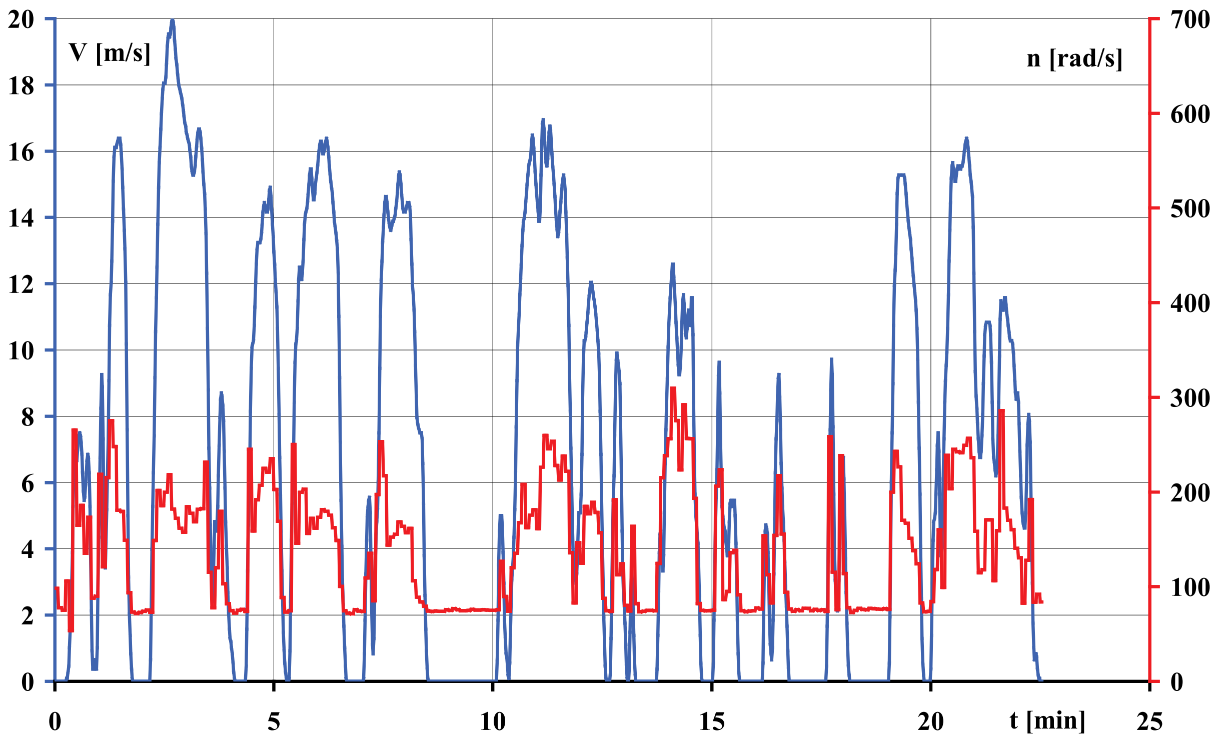

Fig. 5. The driving speed waveform (blue line) and engine speed waveform (red line) during recovery driving

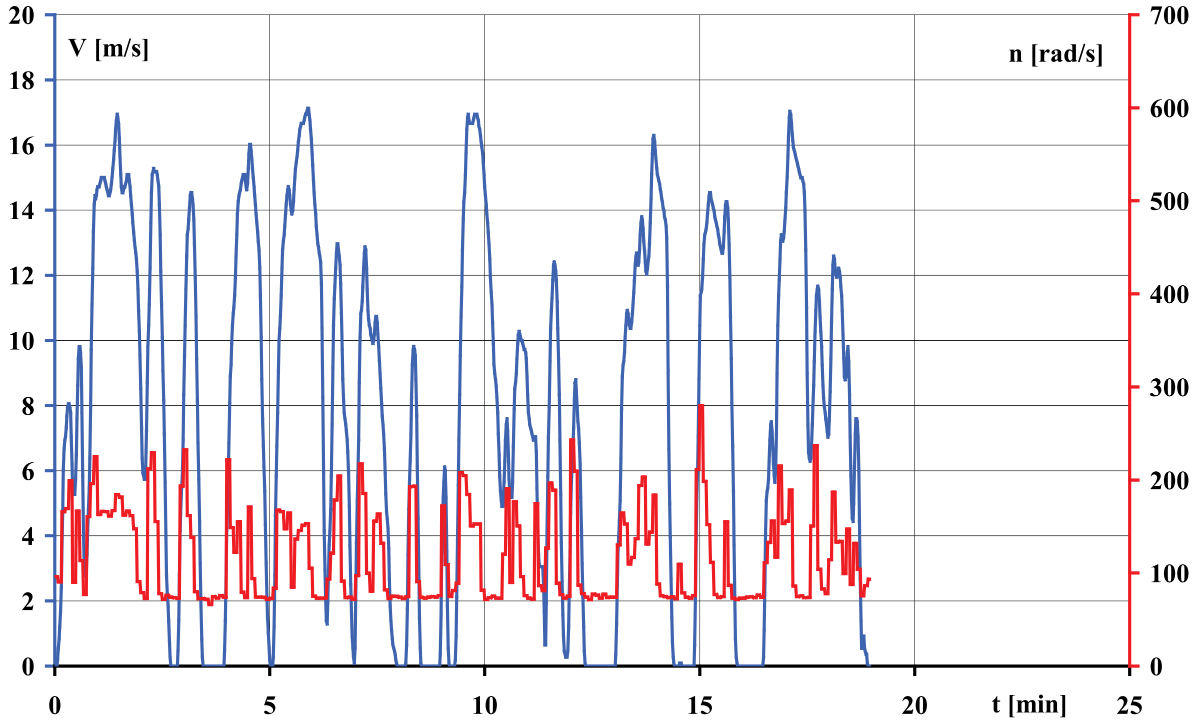

Fig. 6. The driving speed waveform (blue line) and engine speed waveform (red line) during non-recovery driving

Fig. 7 shows how the braking power is being shaped in case of recovery braking. The blue line represents the braking power theoretically possible to use and the red line the power actually recovered in the braking process. As it is shown, almost the entire course is red. This means that almost all of the energy has been used. The calculations show that over 80% of the braking energy was used in the presented example.

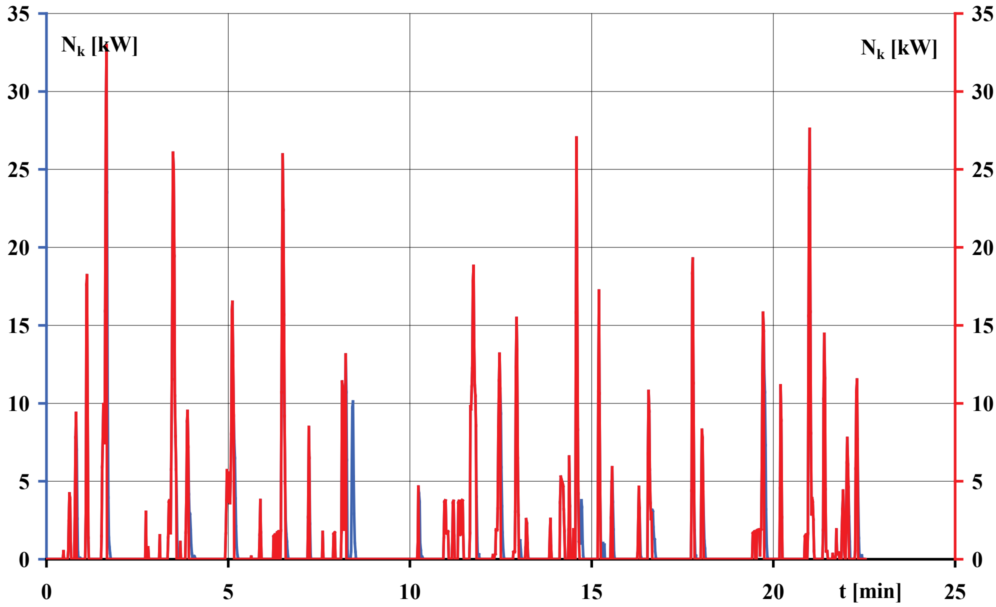

Fig. 7. The kinetic power waveform (blue line) and kinetic power reduced by the power of the friction brake (red line) during recovery driving

For comparison, Fig. 8 shows the braking power in the case of non-recovery driving (line colours are the same as in the previous example). Nearly all the course is blue in this case. This means that almost all-braking power has been generated by the brakes, bypassing energy recovery. In this case, only about 20% of the energy was recovered.

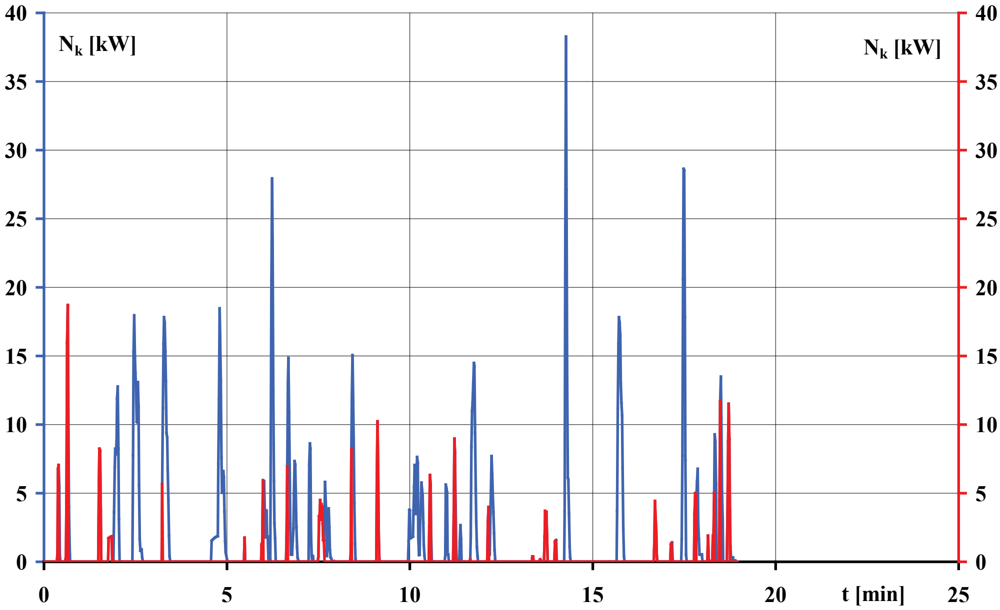

Fig. 8. The kinetic power waveform (red line) and kinetic power reduced by the power of the friction brake (red line) during non-recovery driving

Fig. 9 shows the ratio of total energy recovered to total braking energy in a given test for each test separately. The next bars correspond to the next road tests. Red bars represent braking without recuperation and blue with recuperation. In addition, there is a division into two drivers. There is a clear difference between recuperative and non-recuperative braking. It is also visible the relatively small difference between the amount of energy recovered by individual drivers. In general, it can be stated that the recovery driving mode results in an average of about 60% increase in the amount of recovered energy.

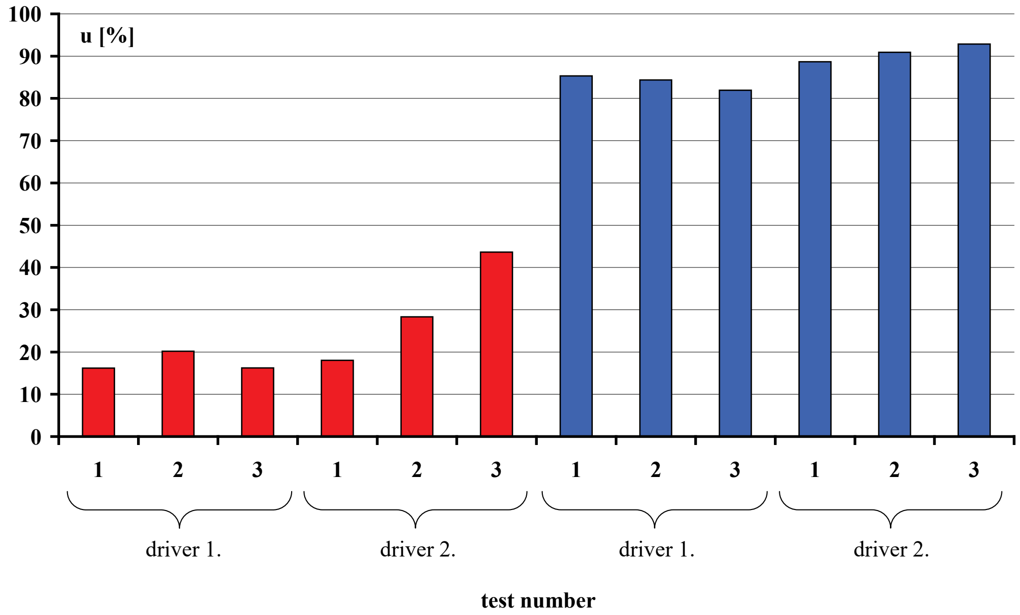

Fig. 9. The values of the ratio of energy recovered to theoretically recoverable energy for recovery (blue bars) and non-recovery (red bars) tests

Computer simulations were also performed which referred presented braking power waveforms to the rest part of the recuperation system model. The problem was how the level of energy stored in the battery is shaping up in the case of recovery and non-recovery driving. This comparison is shown in Figure 10. The graph shows the twelve energy levels in the battery waveforms. Blue lines correspond to recuperation driving and red lines – without recuperation. Consideration concerns the situation when all energy transferred to the battery comes only from the braking process. There is a clear difference between recuperative and non-recuperative driving. Although uniqueness of waveforms performed in both road test groups it is worth noting that differences between groups differences between groups are greater than differences within each groups.

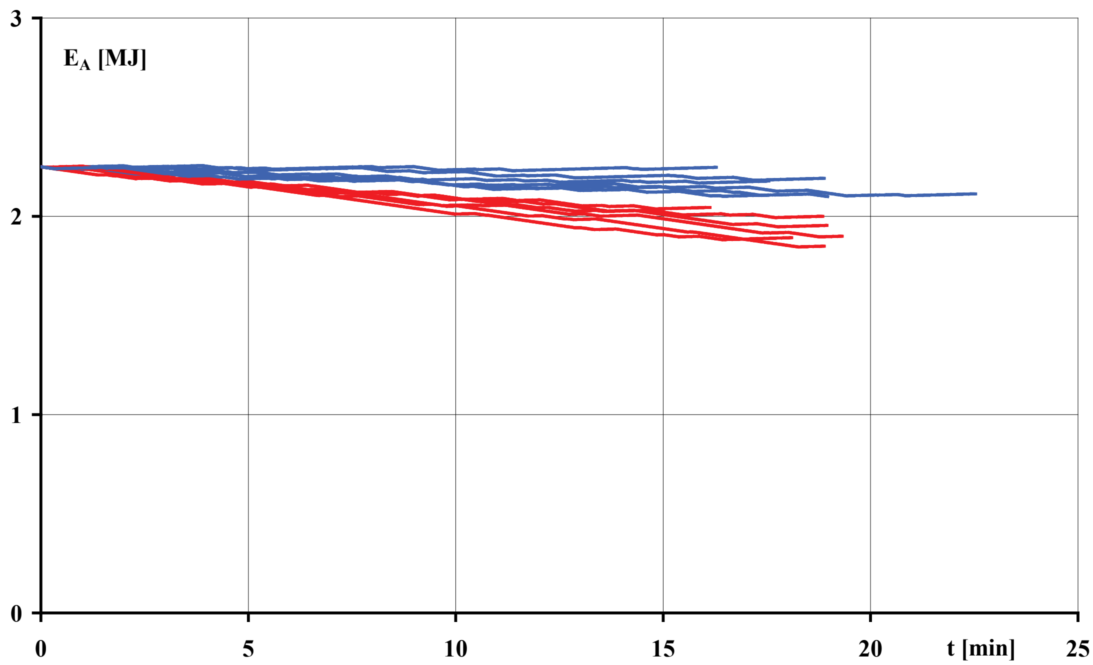

Fig. 10. The energy stored in the battery waveform in the case of six recovery tests (blue lines) and six non-recovery tests (red lines)

4. Summary

The studies that were conducted and their analysis indicate that the way of car driving has a significant impact on the amount of the recovered energy. With recuperative braking, it is possible to use an average of 60% more braking energy. This has a significant impact on the work of the entire recuperation system, including the amount of energy stored in the battery. In the case of a recovery drive, the power level in the battery was approximately constant, with a slight downward trend. However, in the case of driving without recuperative braking the noticeable decrease in battery power was seen each time. It should be emphasized that each time the calculations assumed that the battery is not charged in any other way than braking energy recovery. In addition, the vehicle is not powered in this case from the battery and the only current collectors are devices installed on the car board.

The above observations also lead to the conclusion that it is advisable to train drivers in issues of recuperation braking. This is particularly important for electric cars where energy recovery is in standard now. This can contribute to a significant reduction of the vehicle's energy consumption and in this way increases the range of car. Therefore, this is important from economical and ecological point of view.

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Manuscript received 27 September 2017; approved for printing 12 February 2018