Article citation info:
Adamiec M, Dziubiński M, Siemionek E, Drozd A. Comparative analysis of automotive starting batteries in the aspect of diagnostics research. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2017; 77(3): 5-16, http://dx.doi.org/10.14669/AM.VOL77.ART1

COMPARATIVE ANALYSIS OF AUTOMOTIVE STARTING BATTERIES IN THE ASPECT OF DIAGNOSTICS RESEARCH

ANALIZA PORÓWNAWCZA SAMOCHODOWYCH AKUMULATORÓW ROZRUCHOWYCH W ASPEKCIE BADAŃ DIAGNOSTYCZNYCH

MAREK ADAMIEC[1], MIECZYSŁAW DZIUBIŃSKI[2], EWA SIEMIONEK[3], ARTUR DROZD[4]
Lublin University of Technology

Summary

The paper describes the results of a diagnostics research of automotive starting batteries. For the purpose of the experiment, seven lead-acid batteries of different capacities, starting currents, structures, lengths of operation and levels of exploitation were used. The tests were performed in similar conditions and the preparations included charging up and cleaning the batteries. The experiments were realized on measurement site and in a motor vehicle with the use of battery chargers, electronic testers, diagnoscope, analog and digital measurement apparatus. The tests on measurement site included checking the technical condition with testers and evaluation the voltage-current characteristics. The tests in the vehicle were performed when starting a combustion

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

[2] Lublin University of Technology, Mechanical Engineering Faculty, Department of Automotive Vehicles, Nadbystrzycka 36, 20-618 Lublin, Poland; e-mail: m.dziubinski@pollub.pl

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

[4] Lublin University of Technology; Mechanical Engineering Faculty; Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems; Nadbystrzycka 36, 20-618 Lublin, Poland; e-mail: adrozd.d@gmail.com

engine, when it was idling as well as with the engine turned off but with working electrical receivers. The electrical values for specific batteries and receivers were measured, recorded and calculated by means of a diagnoscope and other instruments. On the basis of the results, a comparative analysis was conducted with special attention paid to the most differing results. The set physical values were compared as well as the recorded changes of voltage and current. Finally, an attempt was made to assess the condition of batteries and their usefulness in a motor vehicle.

Keywords: lead-acid battery, motor vehicle, diagnostics, tester

Streszczenie

W artykule opisano wyniki badań diagnostycznych samochodowych akumulatorów rozruchowych. Do badań wykorzystano siedem akumulatorów kwasowo-ołowiowych, które różniły się między sobą pojemnością, prądem rozruchowym, konstrukcją, czasem eksploatacji i stopniem zużycia. Doświadczenia wykonywano w podobnych warunkach zewnętrznych, a przed testami każdy z akumulatorów został naładowany i zewnętrznie oczyszczony. Badania wykonano na stanowisku pomiarowym oraz w pojeździe samochodowym. Wykorzystano ładowarki akumulatorów, testery elektroniczne, diagnoskop samochodowy oraz przyrządy pomiarowe analogowe i cyfrowe. Badania stanowiskowe akumulatorów polegały na sprawdzeniu ich stanu technicznego za pomocą testerów oraz wyznaczeniu charakterystyki napięciowo-prądowej. Badania w pojeździe przeprowadzono w trakcie rozruchu silnika spalinowego, w czasie jego pracy na biegu jałowym oraz przy unieruchomionym silniku i zasilanych odbiornikach elektrycznych pojazdu. Za pomocą diagnoskopu i jego oprzyrządowania zmierzono, zarejestrowano i obliczono wielkości elektryczne charakteryzujące pracę akumulatora i zasilanych przez niego odbiorników. Na podstawie badań diagnostycznych przeprowadzono analizę porównawczą akumulatorów, ze szczególnym uwzględnieniem wyników badań najbardziej różniących się między sobą. Porównano ze sobą zmierzone i wyznaczone wartości wielkości fizycznych, charakterystyki oraz zarejestrowane czasowe przebiegi napięcia i prądu. Podjęto próbę oceny stanu technicznego poszczególnych akumulatorów i ich przydatności do zastosowania w pojeździe samochodowym.

Słowa kluczowe: akumulator kwasowo-ołowiowy, pojazd mechaniczny, diagnostyka, tester

1. Introduction

Automotive batteries can be divided according to different criteria, one of which is their main purpose. The start of a combustion engine in a standard setup is achieved thanks to standard lead-acid batteries, both serviceable and non-serviceable, which are characterized by small internal resistance and the ability to generate high value of current. Frequent starts in the "start-stop" system and additional receivers require enhanced, heavy-duty EFB (Enhanced Flooded Battery) and AGM (Absorbent Glass Matt) batteries [7, 10]. The positive plates of EFB cells are covered with additional polyester layer which increases the active mass stability of the plate and improves its resistance to cyclic work with high currents. In an AGM battery, sulfuric acid is absorbed in microporous fiberglass separator. Such way of filling the space between electrodes makes it impossible for the electrolyte to leak from a mechanically damaged battery, reduces the tendency to local changes of its density and increases the maximum power of the cell due to small internal resistance of such construction. AGM batteries are also resistant to shocks and frequent charging and complete discharging. What is more, the construction with spiral electrodes is characterized by smaller internal resistance and greater capacity in comparison with the standard, plate version. Such cells are non-serviceable and contain one-way gas valves as well as an internal system of gas recombination, which prevents the loss of water. The cells used in hybrid and electric cars are mainly nickel-metal hydrate batteries and lithium-ion batteries, which are characterized by high storage of energy density and durability, positive capacity to weight ratio, resistance to self-discharging and ability to work in broad temperature range [3, 8]. When batteries are used as power supply of electric driving motor in vehicle, the control and cooling systems become of vital importance as they protect them from overcharging, complete discharging, overloading and high temperature. Different requirements are set for the batteries powering the alarm and control systems in case disconnection of the main cell. Such batteries need not have great capacity or be resistant to loads. Instead, they should be able to operate long time without maintenance. The systems that monitor and control stationary batteries also allow for their constant diagnostics. In some cases, such solutions can be employed in vehicles in order to improve and optimize the work of standard starter batteries [6, 10]. More detailed diagnostics is, however, done by means of tools not available in a vehicle. The research methods can, therefore, be divided into the ones performed on measurement site and in the vehicle. The main method used to involve measuring the electrolyte density in water solution, but it cannot be performed for modern non-serviceable cells. Nevertheless, such test is sometimes done to measure the electrolyte density inside a battery by means of an in-built aerometric float charge indicator or internal sensors [5].

A battery can be generally assessed with the use of electronic testers, but a more detailed diagnosis requires technically advanced diagnoscopes [9]. The most valuable methods take into account various factors, allow to do tests under load and record the values describing the performance of the battery [2]. Computer research programs, mathematical models of batteries and power systems as well as the simulations connected with them are useful in determining the right diagnostic method and designing testing equipment [1, 4]. Different batteries can be diagnosed and compared taking into account their construction, parameters, technical condition, age and operating conditions. The article presents the results of a complex diagnostics research of automotive starter batteries as well as a comparative analysis performed on this basis.

2. Methodology and results

The diagnostic research was conducted for seven lead-acid automotive batteries of different types and condition. The types include standard battery, flat plate AGM and spiral AGM with circular cell section. Four batteries were brand new, whereas three had been used in vehicles as well as other places. One battery of the latter group was serviceable, with open cells. A detailed description can be found in Table 1. The "standard used" battery had been used in the examined vehicle for ten months. The "serviceable used" one had been used in another vehicle for five years and then in a laboratory with small loads for three years. The "worn out" battery had been used in a vehicle for seven years and then stored for one year. All the cells were charged to the limit set by their technical state and tested in similar conditions in the same vehicle.

At the beginning of the tests on measurement site, the batteries were checked with three electronic testers. The results of this stage are presented in Table 1. The testers required both textual and numeral information regarding the cell, especially its type and the norm employed by the producer to establish starting current I_{CCA} (Cold Cranking Amperage). One tester had an in-built resistor to generate load of ca. 100 A and then measure the voltage. The other two measured no-load voltage and calculated the dynamic internal resistance when variable small load was applied. Then, they estimated the actual value of starting current I_{CCA} and provided a textual assessment of the cell's usefulness. In the course of the tests, current-voltage characteristics of the batteries were created by fluently putting load to the maximum level of 100 A. The results are provided in Fig. 1. This test was not performed for the worn-out battery due to its small real capacity and quick discharging. The tests inside the vehicle were done with a diagnoscope. The wires and probes were connected to the terminals of the batteries and 30 A and 1000 A current clamps were placed in specific points of the car's installation. The first task was to measure the resting current of the battery flowing by the control elements and alarm systems of the vehicle in standstill and all other receivers turned off. It is not a typical diagnostic test but it allows to locate any possible damages of isolation and leakages, which makes it possible to prevent battery discharging. The results for all the cells turned out to be similar. The resting current reached from 13 mA to 29 mA while an average and allowed range is from 20 mA to 45 mA.

Table 1. Results of the tests of 12V lead-acid starting batteries performed on measurement site with testers

Battery type and condition	**Standard new**	**Standard new**	**AGM new**	**Spiral AGM new**	**Standard used**	**Serviceable used**	**Standard worn-out**
Capacity [Ah]	50	45	40	44	62	40	75
Voltage before test [V]	12,64 - 13	12,65 - 12,9	12,9-13,2	12,71-13	12,61 - 12,9	12,75 - 13,2	12,74 - 13
Voltage under load [V]	11,4	11,5	11,2	11,5	11,3	10,5	7,6
Voltage after load [V]	12,5	12,6	12,9	12,4	12,6	12,6	12,8
Nominal current CCA [A]	450 (EN)	400 (EN)	220 (EN)	730 (EN)	540 (EN)	200 (DIN)	680 (EN)
Calculated current CCA [A] (tester 1)	444	420	219	788	464	126	84
Calculated current CCA [A] (tester 2)	495	469	242	810	507	142	95
Assessment of battery (tester 1)	positive	positive	positive	positive	positive	replace	replace
Assessment of battery (tester 2)	positive	positive	positive	positive	positive	positive -recharge	broken-replace

The most important test was an attempt to start an engine and record the changes of voltage and current. Diagnoscope also set and displayed on the screen the maximum and minimum values of voltage, maximal starting current and its intensity after starting the engine, the maximal and actual internal resistance and average power at the moment of starting. The selected results that differ significantly are represented graphically in Figures 2-5, whereas the numeral values are given in Table 2. The next test involved recording the voltage and current under rising and dropping load when the engine of the car, therefore also the alternator, were off. Step changes of current and voltage were set after turning on additional electrical receivers in the vehicle. The results that differ significantly are presented in Figures 6-8. The final test done in the vehicle was to observe and record the voltage in terminals of the batteries when the alternator was working and to set the percentage of voltage pulsation. This experiment allowed to assess the batteries' ability to minimize the pulsation of voltage rectified by the diodes in the alternator, and to verify the connections between the alternator and battery. The results that differ significantly are presented in Figures 9-11.

Table 2. Nominal values of batteries and assessed with diagnoscope during an attempt to start an engine

Battery type and condition	**Standard new**	**Standard new**	**AGM new**	**Spiral AGM new**	**Standard used**	**Serviceable used**	**Standard worn-out**
Capacity [Ah]	50	45	40	44	62	40	75
Nominal current CCA [A]	450 (EN)	400 (EN)	220 (EN)	730 (EN)	540 (EN)	200 (DIN)	680 (EN)
Minimum voltage [V]	8,8	8,8	7,8	9,8	8,8	6,8	1,7
Maximum voltage [V]	12,5	12,7	12,6	14,2 (alternator's)	14,3 (alternator's)	12,9	12,7
Maximum starting current [A]	541	501	432	717	586	475	179
Current after starting [A]	3	3	2	2	3	2	2
Permissible internal resistance [mΩ]	9,9	11,1	20,2	6,1	8,2	13,5	6,6
Calculated internal resistance [mΩ]	6,9	7,2	11,2	3,6	6,2	11,2	62,1
Average power [kW]	2,81	2,35	2,45	3,18	2,65	1,77	0,39

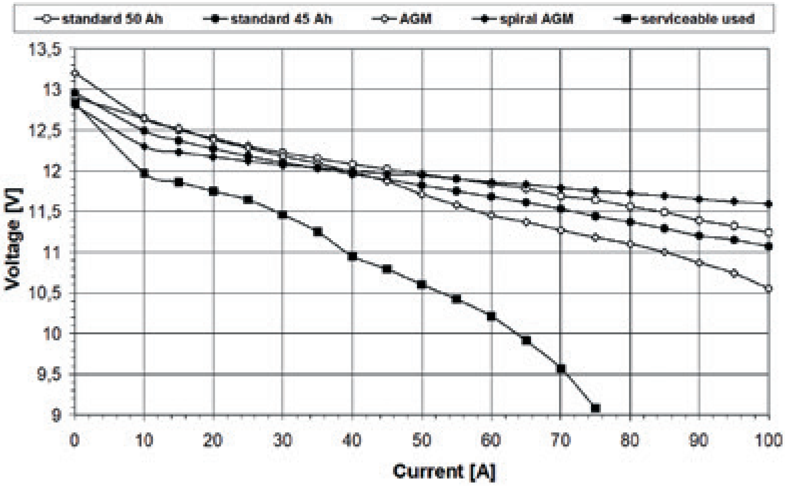

Fig. 1. Voltage-current characteristics of the chosen batteries

3. Analysis of research results

The comparative analysis has been conducted on the basis of tests performed both on measurement site and in an automotive vehicle. The equipment used include electronic and electromechanic measuring instruments testers and a multipurpose diagnoscope with 30 A and 1000 A clamps. Electromotive force, that is, no-load voltage, for all the batteries reached correct values before and after load. Measuring it during or shortly after charging would be pointless as the value increases for a short period of time only to drop after load is applied. As a result, the value can be treated as diagnostic only when it is permanently below the nominal voltage, or when it drops shortly after being charged, without any load. The voltage measured under load is, in turn, the value allowing for the assessment of a battery's condition. The load during tests was increased either fluently, in stepwise fashion or abruptly and significantly. The first way was used to establish the voltage-current characteristics, which is non-linear at the beginning due to energy losses caused by the activation of chemical reactions. After applying the initial load of 10 A, the voltage is not stable. It drops for a few seconds below the established value. Only then is it possible to measure it. In case of bigger loads, voltage stabilizes much quicker, but for the serviceable used battery, not more than 75 A was reached before both current and voltage started decreasing. The characteristic shows that even for lower loads the voltage is not really stable. The characteristics of two standard 50 Ah and 45 Ah batteries are similar. In the case of AGM battery, the characteristics is favourable with lower loads and drops significantly with greater ones. The opposite is true for spiral AGM cell, where after a quick initial drop, the remaining part of the curve is flat and reaches its peak with maximal load (Fig. 1). The biggest and most rapid increase of current intensity appears in the initial stage of the starter motor's operation. The engine can be started successfully when the battery is able to generate sufficiently high current, so it must have enough charge and small internal resistance. The recorded voltage and starting current were similar for the following pairs: standard 50 Ah and 45 Ah, AGM and serviceable used, spiral AGM and standard used.

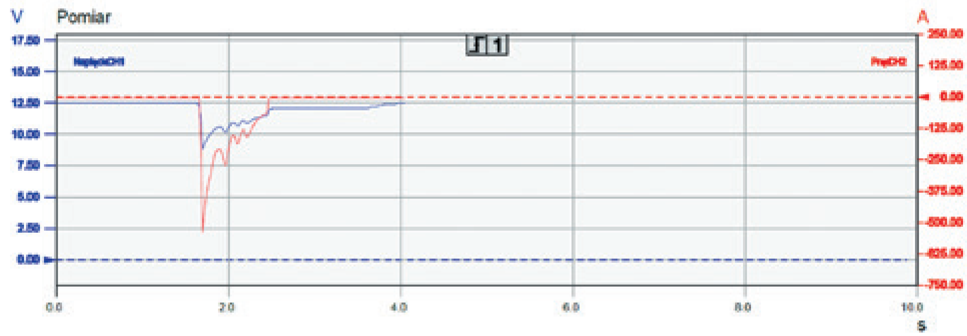

Fig. 2. The courses of voltage and starting current for a standard 50 Ah battery

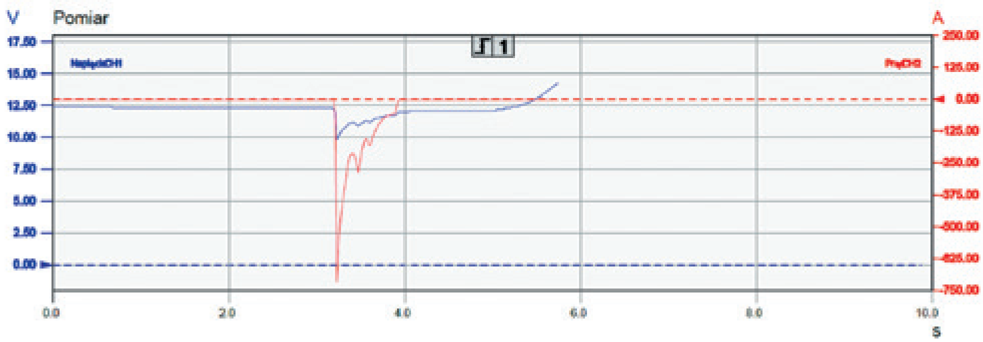

Fig. 3. The courses of voltage and starting current for a spiral AGM battery

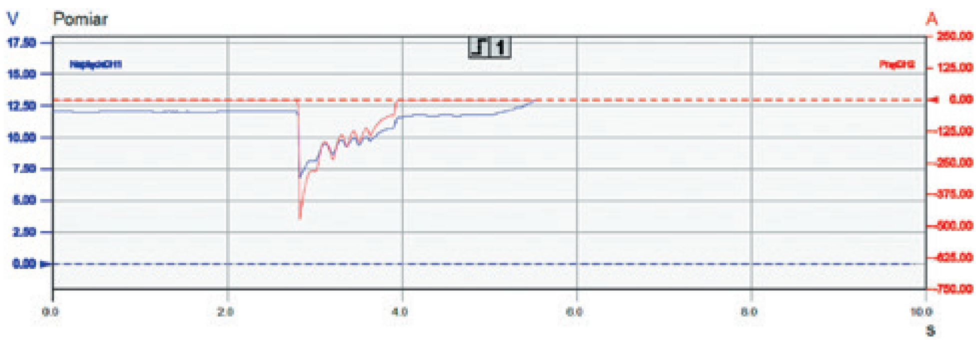

Fig. 4. The courses of voltage and starting current for a serviceable used battery

The chosen graphs are presented as Figures 2-4. Completely different results were obtained for the worn-out battery, which was not able to starting the engine (Fig. 5.). The load was increased in stepwise fashion as new receivers were gradually added. In such case, when an element's resistance depends on current and temperature, temporary increases of current followed by stabilization could be noticed. The graphs of the stepwise voltage and current changes are generally similar. They only differ when it comes to the maximal current intensity for one receiver and the voltage that appears with such current.

The best results and characteristics were obtained from the spiral AGM battery and the worst ones from the standard worn-out (Figures 6-8). A crucial factor that depends on the technical condition of the battery and the level of charge is its internal resistance, which for the working cells reached from 3,6 mΩ to 11.2 mΩ, and for the worn-out battery was 62.1 mΩ. The resistance was calculated with diagnoscope during attempts to starting the engine. The electronic testers used, which also do not put much load on a battery, are also able to calculate internal resistance according to a given algorithm but they display information in simpler, more understandable fashion. The chemical reactions that take place inside a cell and the energy required at their various stages also have an influence on internal energy losses.

Voltage pulsation measured on terminals of the batteries when the alternator was working stems from the process of rectification carried out by the rectifying system of the alternator. Short impulses with high amplitude and voltage fluctuation are reduced by the battery, but the amplitude also depends on the length of the cables and correctness of connections.

In the case of four new batteries, voltage pulsation did not exceed 1% and for the two used ones, greater values (up to 3%) were recorded. Minor interferences that occasionally appear and cannot be reduced are caused by overvoltage during cummutation phenomena on the diodes of the rectification system (Fig. 9-11).

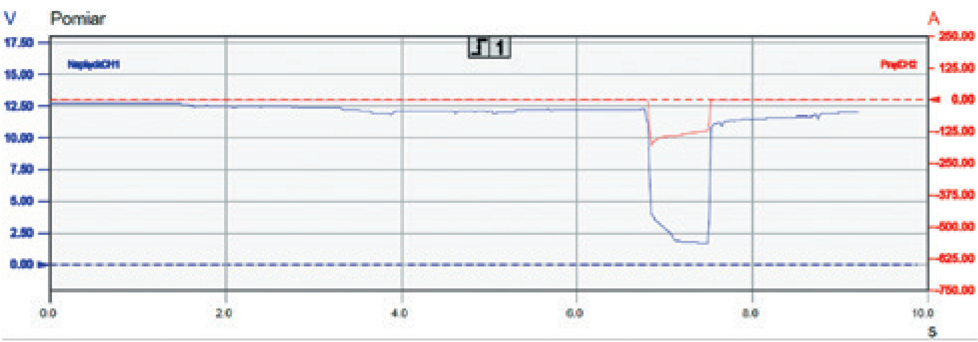

Fig. 5. The courses of voltage and starting current for a standard worn-out battery

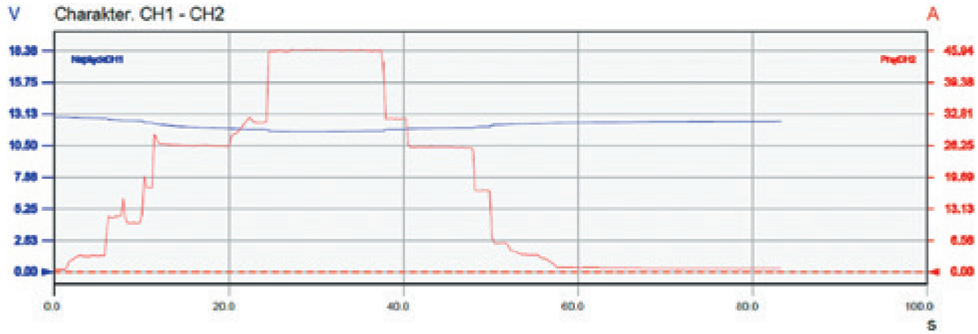

Fig. 6. Step voltage and current changes for a standard 50 Ah battery after adding and removing receivers

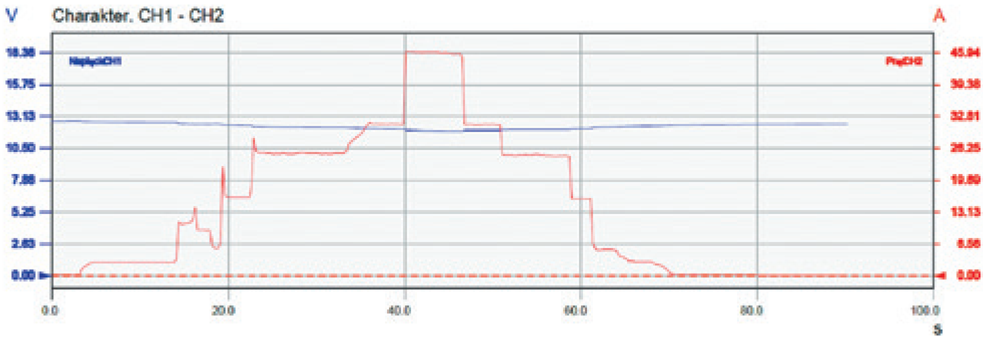

Fig. 7. Step voltage and current changes for a spiral AGM battery after adding and removing receivers

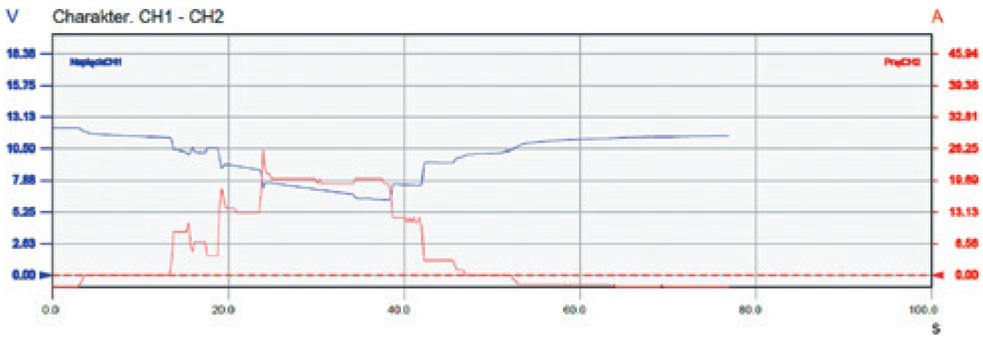

Fig. 8. Step voltage and current changes for a standard worn-out battery after adding and removing receivers

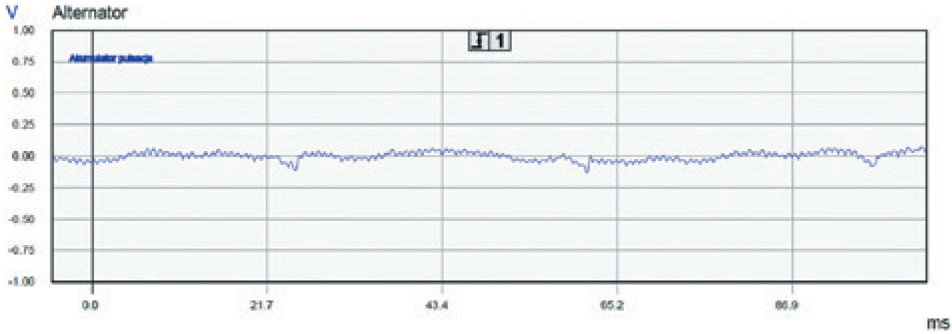

Fig. 9. Ripple voltage on the terminals of a standard 45 Ah battery with working alternator (14,3V; 0,2A; pulsation 0,96%)

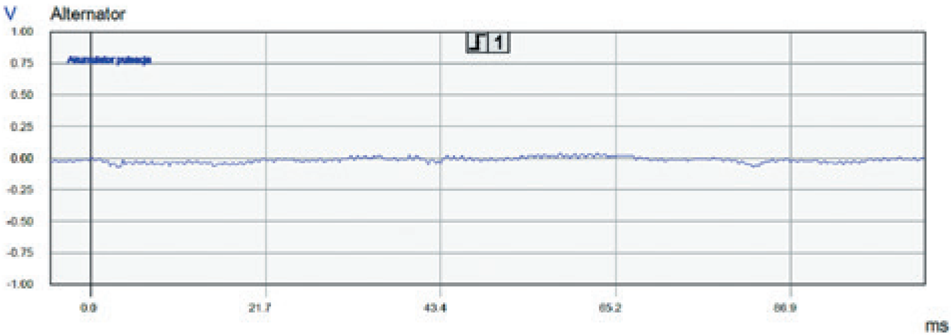

Fig. 10. Ripple voltage on the terminals of a spiral AGM battery with working alternator (14,3 V; 5,9 A; pulsation 0,34%)

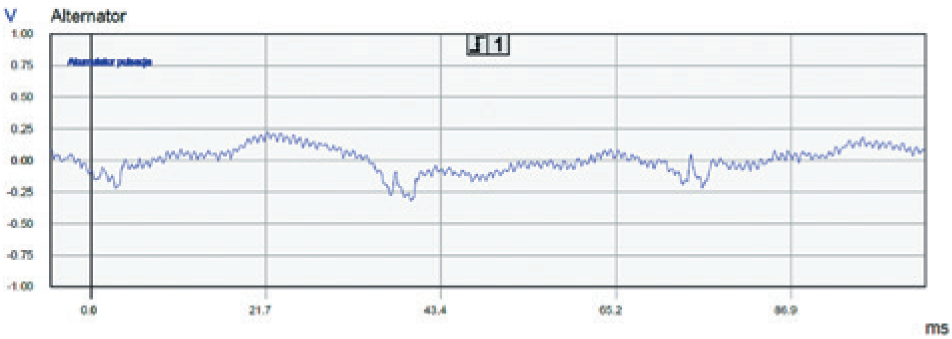

Fig. 11. Ripple voltage on the terminals of a serviceable used battery with working alternator (14,3 V; 0,4 A; pulsation 2,39%)

4. Conclusions

An examination with the use of testers allows for a general assessment of a battery, and its results depend on the methods and algorithms used by the device. The results of the tests confirmed the predicted technical condition of the batteries and correctly assessed the possibility of further use in a motor vehicle. The starting current calculated by two testers were slightly different for the same battery but in the main no opposing in proportion to nominal value. In the case of four brand-new batteries, the calculated values were generally higher than the nominal values. For the used ones, however, they were progressively smaller depending on the level of wear. The current-voltage characteristics proved to be a valuable diagnostic method as when the current is flowing all along, its intensity consecutively increases. As a result, it is possible to notice the "voltage reaction" of battery, namely how much does the potential difference diminishes, how long does it take to stabilize under a given load and what current can be stably achieved. The best diagnostic method is to combine the measuring, calculating and graphical techniques in one device, which allows to assess different physical values and monitor their changes. The main test should be performed when the engine is started as it is the major task of a battery. The spiral AGM battery was able to supply the starter motor with the biggest current combined with the lowest voltage drop, which made it possible to start the engine in the shortest time. Among the standard batteries, the smallest internal resistance and the fastest starting was noticed in the battery that had been used in a vehicle for 10 months. Slightly worse results were recorded, however, when the starting current was calculated with testers. The standard worn-out battery was not able to starting the engine due to high internal resistance of 62.1 mΩ and the voltage drop to just 1.7 V. The analysis of the results of two AGM batteries shows better performance of the spiral type. It must be taken into account, however, that the flat plate AGM battery had slightly smaller capacity and over three times smaller nominal starting current. Two new, non-serviceable standard batteries with similar capacities produced very similar, satisfactory results. The serviceable battery, which had already been used in a vehicle for five years and started causing problems there, proved suitable only for work in a laboratory, powering small receivers. Having operated in such conditions for three years, it was recharged and successfully used to start the engine of a vehicle. This attempt shows that an unequivocal assessment of a battery may be difficult as if it was permanently reinstalled in a vehicle, it might not work properly. The history of the tested batteries was known, but if the technical condition is unknown, alternative activities described in the article can be employed depending on circumstances.

The full text of the article is available in Polish online on the website
http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie
http://archiwummotoryzacji.pl.

References

[1] Chmielewski A, Gontarz S, Gumiński R, Mączak J, Szulim P. Badania elektrochemicznych magazynów energii. Przegląd Elektrotechniczny. 2016; 92(10): 231-234.

[2] Gładysek J, Gładysek M. Poradnik diagnostyki samochodowej - pomiary oscyloskopowe. Wydawnictwo Bosch. 2008.

[3] Jaroszyński L. Akumulatory litowe w pojazdach elektrycznych. Przegląd Elektrotechniczny. 2011; 87(8): 280-284.

[4] Kasprzyk L, Bednarek K, Burzyński D. Symulacja pracy akumulatorów kwasowo-ołowiowych. Przegląd Elektrotechniczny. 2016; 92(12): 61-64.

[5] Marcos J, Cao-Paz A. M, Lago A, Nogueiras A, Peñalver C M. Fiber optic sensors for diagnosis and maintenance in lead-acid batteries. 2nd IFAC Workshop on Advanced Maintenance Engineering, Services and Technology. 2012; Universidad de Sevilla, Spain.

[6] Nagashima S, Takahashi K, Yabumoto T, Shiga S, Watakabe Y. Development and field experience of monitoring system for valve-regulated lead–acid batteries in stationary applications. Journal of Power Sources. 2006; 158: 1166-1172.

[7] Schaeck S, Stoermer A O, Hockgeiger E. Micro-hybrid electric vehicle application of valve-regulated lead–acid batteries in absorbent glass mat technology: Testing a partial-state-of-charge operation strategy. Journal of Power Sources. 2009; 190: 173-183.

[8] Świerżewski M. Chemiczne źródła prądu elektrycznego. Dodatek do miesięcznika "INPE". SEP; 2013; 42.

[9] Trzeciak K. Diagnostyka samochodów osobowych. Warszawa: WKIŁ; 2013. 392.

[10] Wróblewski P. Eksploatacja i diagnostyka akumulatorów VRLA z czujnikiem akumulatora IBS w pojazdach z systemem start-stop. Auto Moto Serwis. 2016; 1: 30-35.