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Research Article

DEVELOPMENT OF A COST-EFFECTIVE HEAVY-DUTY LEAD-ACID BATTERY CAPACITY TESTER

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Batteries are the energy source that provides energy to the vehicle for the first movement. Batteries used in motor vehicles nowadays are usually lead-acid batteries. This paper introduces the basic components of lead-acid batteries and describes the concept of a battery capacity test. The general definition of the standard for testing, EN50342, and the required conditions are presented. Furthermore, a cost-effective capacity tester for heavy-duty lead-acid batteries in compliance with the standard was developed and introduced.

Keywords: Battery Capacity, Lead-Acid Battery. Heavy-Commercial Vehicles Battery

1. Introduction

A battery is the only part to which the vehicle is dependent, regardless of vehicle type, and its technical characteristics have changed little over time. If your battery runs out, you will stay on the road. You can find the auto electrician, the tire repairman anywhere, anytime, but the battery is not something that can be found on the road. We all know how sad your plans become the next day when you forget to close your headlights or radio.

Battery failures are in part influenced by driving habits, the liberal use of auxiliary loads, hot climate conditions, start-stop, and battery mount. Sometimes a battery failure can be caused by the buildup of conductive materials across the battery posts that induce an ionic discharge. Even under the best conditions, a quality battery ages and this manifests itself in a gradual drop of capacity. A common failure of the battery is the capacity fade. The battery does not work in accordance with the capacity produced can be given as an example. For example, a battery with a capacity of 220Ah, according to the European Standard (EN50342) for 20 hours until 10.5 V below 11 A must give a rating in the battery capacity test [1].

These tests are realized after a long process in the laboratory environment. This study aims to present the practical solution of the tests and to realize the tests in a short time with low-cost and high efficiency.

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2. Instructions

In common parlance, the term ‘automotive battery’ is usually taken to mean a battery on-board a road vehicle. The automotive battery in a vehicle for which the motive power is provided by a combustion engine is generally referred to as an SLI battery, from the basic electrical functions of starting (S), lighting (L), and ignition (I) [2].

Today, the automotive battery preferred for SLI function in cars is a flooded, 12-V design and comprises six lead-acid cells in a monobloc container. This battery is compatible with the vehicle electrical system that operates in the voltage range from about 12 to 14 V. Until around 1970, 6-V systems were also in use. In European trucks and buses, on the other hand, it is common practice for two, 12-V batteries to be connected in series to achieve a nominal voltage of 24 V [2].

The lead-acid battery was developed by the French physician Gaston Planté using metallic lead and sulfuric acid as an electrolyte in 1859 [3]. Camille Faure proposed the concept of a glued plate [4]. Lead-acid was the first rechargeable battery for commercial use. Despite its advanced age, lead chemistry continues to be in wide use today.

Lead-acid batteries consist of a positive electrode composed of lead-dioxide (PbO_2), a negative electrode composed of metallic lead (Pb), and a dilute solution of sulfuric acid electrolyte [5]. The overall discharge reaction in a lead-acid battery is:

$$\mathrm{PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O} \tag{1}$$

The grid structure of the lead-acid battery is made from a lead alloy. Pure lead is too soft and would not support itself, so small quantities of other metals are added to get the mechanical strength and improve electrical properties. The most common additives are antimony, calcium, tin, and selenium. Chemistry and principal components of a lead-acid battery can be seen in Fig.1 [6].

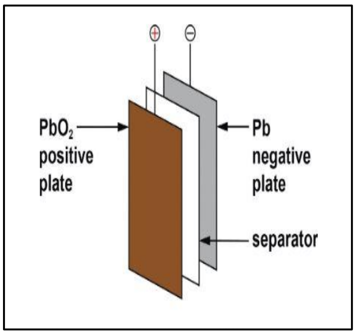

Figure. 1. Chemistry and principal components of a lead-acid battery.

There are good reasons for its popularity; lead-acid is dependable and inexpensive on a cost-per-watt base. Few other batteries deliver bulk power as cheaply as lead-acid, and this makes the battery cost-effective for automobiles, golf cars, forklifts, marine, and uninterruptible power supplies (UPS) [7].

The major advantage of lead-acid batteries is that it does not require any water maintenance. This is because the oxygen produced at the positive plates during charging is reduced to water at the negative plates [8].

Lead-acid batteries are capable to deliver high power; they are reliable and easy to produce. Specific battery parameters for electric vehicles are given in Tab. 1 [9]. The resources for their manufacture are practically unlimited. Almost 98% of the materials used in a lead-acid battery are recyclable.

Table I. Specific Battery Parameters for Electric Vehicles

Battery Type	Specific Energy (Wh/kg)	Specific Power (W/kg)	Energy Density (Wh/l)	Cycle Life	Efficiency
Lead-Acid	35	150	40-100	400	80%
Nickel-Cadmium	50	400	50-150	1500	70%
Nick. M. Hydride	90	300	140-300	1000	75%
Nickel-Zinc	75	500	280	500	70%
Lithium-Ion	200	400	250-693	1500	93%

Almost 98% of the materials used in a lead-acid battery are recyclable. Every industrial country has a well-organized closed-loop lead recycling system for the manufacture of lead-acid batteries, collection of spent batteries, their recycling, and subsequent manufacture of new batteries using recycled materials. A lead-acid battery can store its energy for a very long time [10].

The major disadvantage of the lead-acid battery is that lead has a very high atomic weight, which reduces the specific energy and power of the battery [10].

Nowadays, hundreds of millions of lead-acid batteries are produced worldwide, which makes the lead-acid battery the most successful power source of all time.

EN50342, this European Standard applies to lead-acid batteries with a nominal voltage of 12 V, used primarily as a power source for the starting of internal combustion engines, lighting, and also for auxiliary equipment of internal combustion engine vehicles. These batteries are commonly called “starter batteries”. Batteries with a nominal voltage of 6 V are also included within the scope of this standard. All referenced voltages need to be divided by two for 6 V batteries [1].

This European Standard applies to batteries for the following purposes: Batteries for passenger cars, batteries for commercial and industrial vehicles.

This European Standard consists of six separate parts. These sections are explained below.

EN 50342-2, Lead-acid starter batteries – Part 2: Dimensions of batteries and marking of terminals

EN 50342-4, Lead-acid starter batteries – Part 4: Dimensions of batteries for heavy vehicles

EN 50342-5, Lead-acid starter batteries – Part 5: Properties of battery housings and handles

EN 50342-6, Lead-acid starter batteries – Part 6: Batteries for Micro-Cycles Applications [11].

Authors are obliged to use System International (SI) for Units (including Non/SI units accepted for use with the SI system) for all physical parameters and their units.

2.1. EN50342-5.1 Capacity Test

The information on the capacity test of lead-acid batteries is in EN50342-5. The requirements for capacity testing are given below.

EN50342-5.1.1: Throughout the test, the battery shall be placed in a water bath maintained at a temperature of 25 ± 2℃. The terminal base of the battery shall be at least 15mm but not more than 25mm above the level of the water. If several batteries are in the same water bath then the distance between them and also the distance to the walls of the shall be at least 25mm.

EN50342-5.1.2: The battery shall be discharged with the current kept constants at +2% of the nominal value until the terminal voltage falls to 10,50 V + 0,05 V. The duration t(H) of this discharge shall be recorded. The beginning of the discharge shall take place within a period of 1h to 5h from the time of the end of charging [12].

$$I_N = \frac{C_N}{20h} \tag{2}$$

EN50342-5.1.3: The capacity CE is formulated as following:

$$C_E = t \,.\, I_N \tag{3}$$

Under these conditions, a microprocessor-controlled tester was designed to perform the test.

3. Material and Method

In design, ATmega328, a microcontroller of Microchip company, is used considering the low cost and easy to find. ATmega328's ease of programming, variety of shields, and low-cost provided an advantage in the design. Temperature sensor, current sensor (ACS712), and voltage sensor were used for collecting data of temperature, current, and voltage, respectively. SD (Memory card) card module was integrated into the microcontroller to record data from the sensors. MOSFET (Field Effect Transistor) component was used to control the current following the EN50342 standard. Moreover, a load element of 13 A-12 V was added to the circuit.

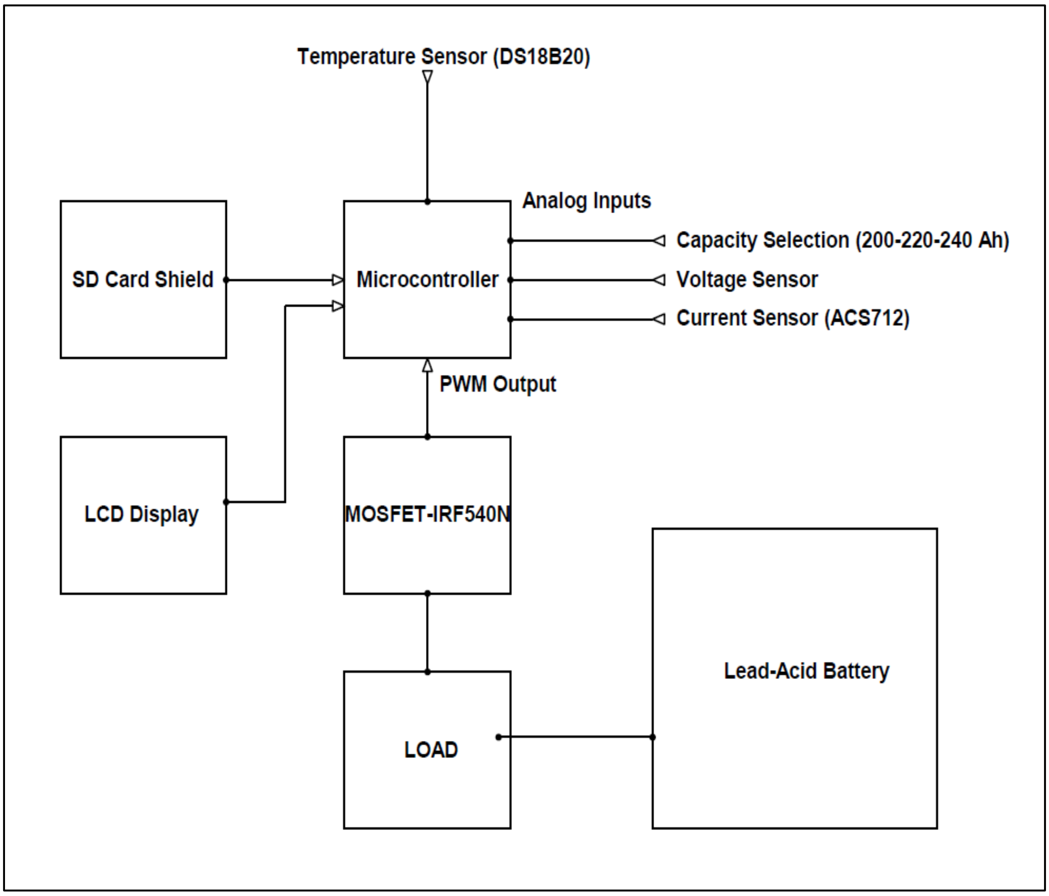

Figure. 2. Hardware diagram

The hardware diagram is shown in Fig. 2 and its control block diagram is shown in Fig 3. In the designed circuit, the load consists of 13 A. This load current value is determined according to a nominal current value which is determined by the capacity of the battery. A voltage divider circuit is designed to measure the voltage of the battery. This voltage divider circuit is reduced by ¼ of the battery voltage provides appropriate voltage to analog inputs of the microcontroller [13,14]. There is a current sensor

(ACS712) that measures the load current connected to the load. The current and voltage values which are measured are recorded to the SD card shield at 1-second intervals.

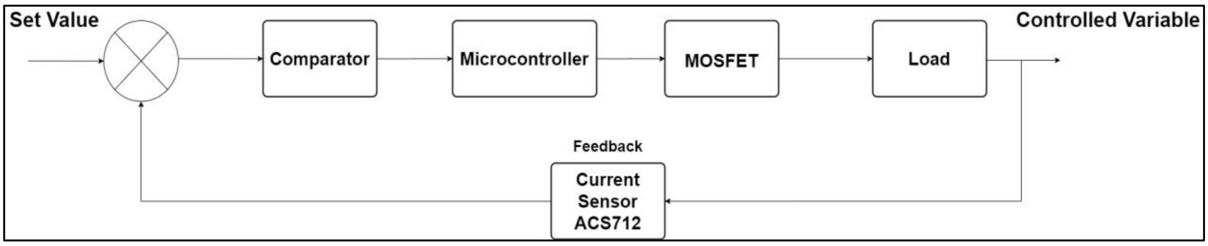

Figure. 3. Block diagram of current control

The tester works properly with three different battery capacities. These capacities are 200Ah, 220Ah, and 240Ah. The nominal current value is fixed according to the selected capacity value. The battery capacity tester is shown in Fig. 4.

Figure. 4. Battery capacity tester

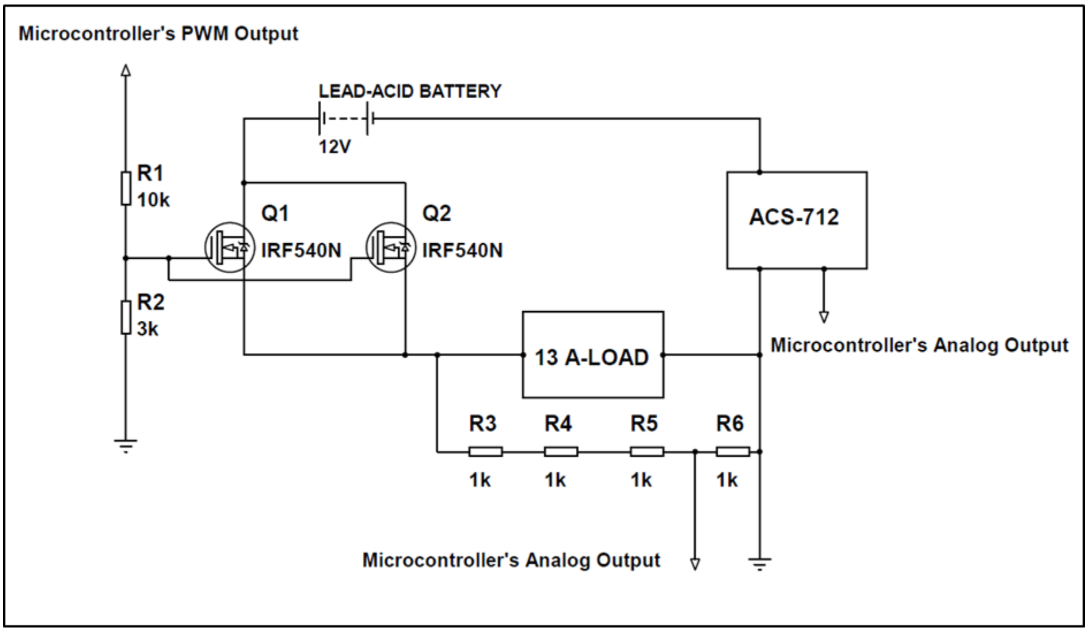

Figure. 5. Battery capacity tester circuit diagram

The most important function of the circuit keeps the current value under the requirements of the test. This function is realized with MOSFET. MOSFETS are driven PWM signal from the microcontroller. Depending on the current drop or rise, the duty cycle PWM is increased or decreased. MOSFET keeps the current constant according to the tolerance range [15,16].

According to EN50342-5.1.1, the battery is placed in a water bath. The pre-condition is that the temperature of the water must be 25 ± 2°C was provided test started. Therefore, the battery in the water bath is put in the temperature test chamber Figure 6. The temperature test chamber is set at 25°C. The thermocouple, which is the temperature sensor, is immersed in water. If the water temperature is in the range of 25 ± 2°C, the test starts.

Fig. 6. The battery in the test chamber

4. Test Results

In Fig. 7, the voltage-current graph in the capacity test of a used battery with a capacity of 220 Ah is shown. The duration of the capacity test is 13h 50m 19s, which equals 13.83 h. The capacity of the battery is calculated according to equations 4, 5, and 6.

$$C_E = \int_0^{\text{Elapsed Time (h)}} I_N \, dh \tag{4}$$

$$C_E = \int_0^{13.83\ (h)} 11 \, dh \tag{5}$$

$$C_E = 11\ [\,h\,]_0^{13.83\ (h)} = 152.16\ \text{Ah} \tag{6}$$

Although produced as 220 Ah capacity, the battery capacity was found 152.16 Ah. According to the result, the battery does not meet the requirement EN50342-5.1 capacity test and failed.

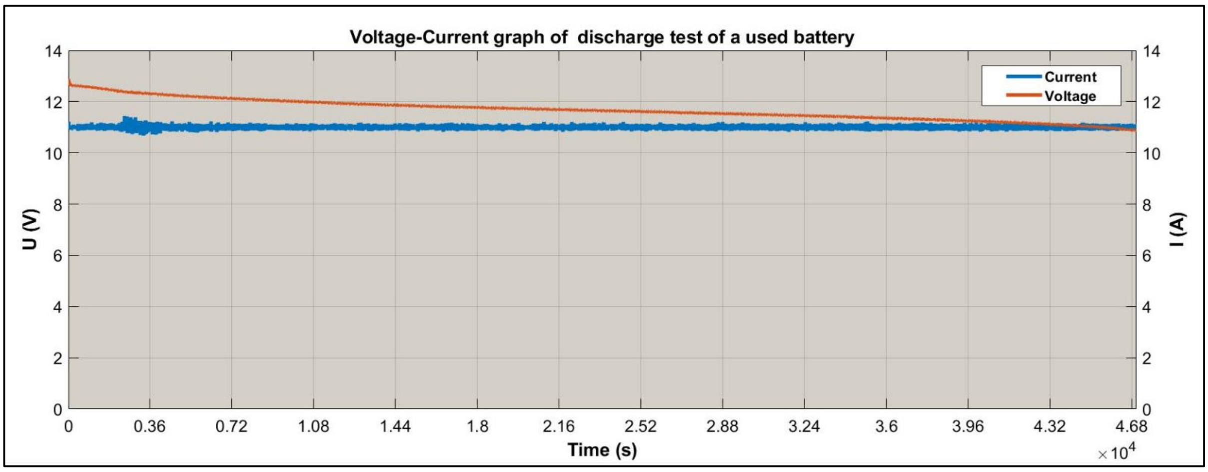

Figure 7. Voltage-Current graph of discharge test of a used battery – 220 Ah

In figure 8, the voltage-current graph in the capacity test of a new battery with a capacity of 220 Ah is shown. The duration of the capacity test is 20h 03m 17s, which equals 20.05h. The capacity of the battery is calculated according to equations 7, 8, and 9.

$$C_E = \int_0^{20.05\,(h)} 11\, dh \tag{7}$$

$$C_E = 11\,[\,h\,]_0^{20.05\,(h)} = 220.55\ \text{Ah} \tag{8}$$

The battery capacity was found at 220.55 Ah. According to the result, the battery does meet the requirement EN50342-5.1 capacity test and passed.

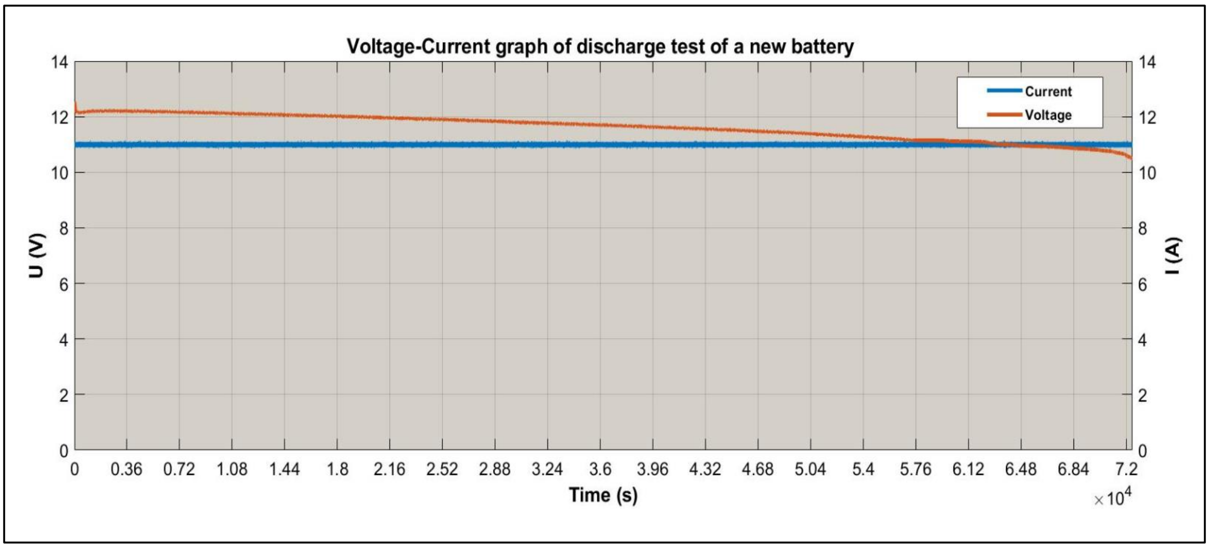

Figure 8. Voltage-Current graph of discharge test of a new battery – 220 Ah

5. Conclusion

In this study, the advantages and disadvantages of lead-acid batteries used in the automotive industry were compiled. To determine one of the battery malfunctions, capacity reduction, or capacity failure, test standards following international standards were researched and the test conditions of the standards were examined. A low-cost microcontroller-controlled capacity test device was designed and produced following the EN50342 standard of the European Electrotechnical Standardization Committee, which is responsible for standardization in the field of electrical engineering.

Lead-acid batteries with a capacity of 220 Ah passing under two different operating conditions were tested with a capacity tester. It was concluded that the capacity result of the battery that was used for a long time was obtained as 152.16 Ah and it could not pass the capacity test. At the end of the capacity test result of the other lead-acid battery, its capacity value was obtained as 220.55 Ah and it was concluded that it was acceptable to pass the capacity test.

In conclusion, the capacity test of the battery was realized following the EN50342. The practical solution for tests has been introduced and the test process has been shown. A cost-effective capacity tester for heavy-duty lead-acid batteries in compliance with the standard was developed.

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