ELSEVIER

Journal of Power Sources 53 (1995) 367–375

JOURNAL OF POWER SOURCES

Optimized batteries for cars with dual electrical architecture

J.P. Douady, C. Pascon, A. Dugast, G. Fossati

Compagnie Européenne d'Accumulateurs, 18 quai de Clichy, BP 306, Clichy 92111, France

Accepted 13 September 1994

Abstract

During recent years, the increase in car electrical equipment has led to many problems with traditional starter batteries (such as cranking failure due to flat batteries, battery cycling etc.). The main causes of these problems are the double function of the automotive battery (starter and service functions) and the difficulties in designing batteries well adapted to these two functions. In order to solve these problems a new concept — the dual-concept — has been developed with two separate batteries: one battery is dedicated to the starter function and the other is dedicated to the service function. Only one alternator charges the two batteries with a separation device between the two electrical circuits. The starter battery is located in the engine compartment while the service battery is located at the rear of the car. From the analysis of new requirements, battery designs have been optimized regarding the two types of functions: (i) a small battery with high specific power for the starting function; for this function a flooded battery with lead–calcium alloy grids and thin plates is proposed; (ii) for the service function, modified sealed gas-recombinant batteries with cycling and deep-discharge ability have been developed. The various advantages of the dual-concept are studied in terms of starting reliability, battery weight, and voltage supply. The operating conditions of the system and several dual electrical architectures have also been studied in the laboratory and the car. The feasibility of the concept is proved.

Keywords: Starter batteries; Service batteries; Dual electrical architecture

1. The starter battery today

1.1. Starter battery functions

The starter battery of a car with an internal combustion engine has, at the moment, two separate functions (Fig. 1). The first is the starting function; it consists in starting up the internal combustion engine. The second is the service function; it consists in ensuring an electrical buffer function between the electrical energy production system of the car (alternator) and the car electrical equipment (e.g., lighting, signaling, fans, demisting, defreezing, various actuators, radio, telephone, etc.). This second function is used in two situations:

(i) when the engine is stopped and when an electrical energy supply is required for signaling, lighting, radio, telephone, etc.;

(ii) when the electrical power supplied by the alternator is lower than that needed by electrical equipment switched on (negative electrical balance); this operating condition can occur at engine idle (when electrical power available from the alternator is appreciably lower than maximal power) and in climatic conditions (night, rain, etc.) that require the use of much electrical equipment (lighting, fans, demisting, etc.).

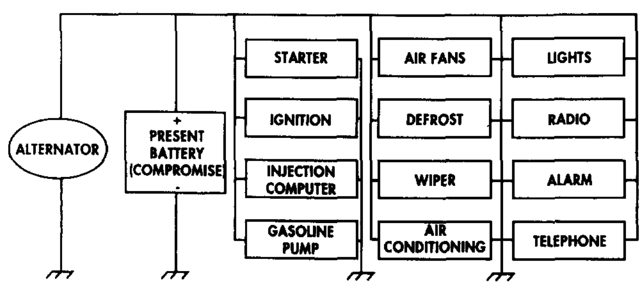

Fig. 1. Present electrical architecture.

The starting function requires a high electrical power supply during a short time, typically 1.5–5 kW (this means a few hundred amps for a 12 V battery) during a few seconds. The service function requires low or medium energy levels (this means intensities from a few milliamps to several tens of amps) during more or less long periods (from a few seconds to several days), but in a repetitive way. Such operating conditions lead

SSDI 0378-7753(94)02002-K

to cycling of the battery. Until the end of the 1970s, the starting function was the main function of the car battery. But during the last fifteen years, the importance of the service function has increased widely. This evolution is due to a constant increase in the car electrical equipment level. Analysis for the foreseeable future shows that this trend is going to continue during the next five or ten years.

The increase in electrical equipment is related to different types of functions:

(i) total or partial electrification of functions that were previously accommodated by mechanical or hydraulic devices (braking, steering, engine cooling fan, fuel pump, engine control, etc.);

(ii) development of safety and security equipment, e.g., lighting, signaling, demisting, defreezing of rear window and wind screen, driving assistance, etc.;

(iii) development of comfort and convenience equipment, e.g., heating, air conditioning, heated seats, radio, telephone, fax, alarm, various actuators (windows, seats, etc.).

Table 1 shows an evolution analysis, versus time, of the electrical power needs for a top-of-the-line car.

Table 1
The increase in electrical power needs of cars

Years	1980	1990	2000
Electrical power needs (kW)	0.7–1	1.2–2	2.5–4.5

It is also necessary to consider the emergence of a new potential third function for the car battery: the power supply for the electrical heating devices for exhaust-gas depollution catalysts. This function related to the inefficiency problems of current catalytic systems, when the engine is cold, could be developed during the next years. From the information available at the moment, it can be estimated that the electrical power requested for this function is a few kW (viz., 2–4 kW). That is roughly the same values as the power needed for the starting, but the energy requested for the electrical heating of catalysts is greater as the duration of supply is several tens of seconds.

1.2. Operating conditions of the starter battery

During the last few years, the operating conditions of starter batteries have changed in an important way. First, research into improvements in car aerodynamics has led to reduced air flows in the engine compartment and to a greatly increased average operating temperature of the battery. This situation is enhanced by the reduced space for equipment under the hood and the increase of engine operating temperatures. Moreover, the reduction in the room available in the engine compartment due to the shape change of the car bodies (to increase the air penetration ratio) and the increase in the amount of equipment under the hood leads to a less advantageous location of the battery in the engine compartment.

From the starting function point of view, if electronic injection has resulted in easier starting of gas engines, the development of large diesel engines with anti-pollution devices has given rise to very high starting power requirements.

1.3. Problems with current starter batteries

Nowadays the current starter battery is trade-off which is becoming less and less satisfactory.

1.3.1. design

It is becoming more and more difficult for battery producers to design products that are well adapted to the two battery functions. The starting function requires a battery design with many thin plates, but the service function requires an energy battery with fewer thicker plates better suited to the cycling.

1.3.2. Reliability of starting function

The likelihood of non-starting due to a flat battery is becoming greater and greater. Analyses carried out by car manufacturers are showing that 3–5% of cars experience a non-starting fault during the first warranty year. A study of batteries, taken from cars for non-starting reasons, has shown that in 80% of the cases the batteries are simply discharged. This partial or total discharge is due either to a negative electrical balance or to substantial quiescent loads. The starter function is becoming less and less reliable.

1.3.3. Battery cycling

The increase in the number of electrical devices has resulted in a battery cycling. This cycling has two causes: (i) the operating times with negative electrical balance (which can be partially reduced by an optimization of the alternator power, especially in the idle region); (ii) the operating of key-off equipment (alarm, various electrical devices, telephone, fax, navigation systems). This cycling leads to a reduction in the life expectancy of the battery that, in turn, cannot be optimized for such use.

1.3.4. Battery location

The reduction of the room available in the engine compartment suggests alternative battery locations, e.g., in the passenger compartment, boot, etc. The consequences of such re-location are the use of long cables with large cross section and an increase in battery size in order to balance the voltage drop in cable. This problem is particularly critical for large diesel engines.

1.3.5. Adjustment between battery range and car range
At the moment, a car can be fitted out with very different levels of electrical equipment for the same type of engine, or with the same level of equipment it can be powered by different types and sizes of engine. Therefore, it is becoming difficult to choose a battery (cranking power, capacity) that matches well the car design.

1.3.6. Supply voltage of electronic system
Due to the voltage drop in the car electrical network during cranking operation, car electronic systems have to be designed to operate at fairly low voltages (6–7 V). This leads to design problems and increases in cost.

2. Dual-concept — principle and advantages

2.1. Principle

The principle of the dual-concept is to separate the two functions of the current starter battery by using two batteries with different design. One battery is dedicated to the starting function, and the other is dedicated to the service function. The requirements for the two batteries are as follows (see Figs. 2 and 3).

2.1.1. Starter battery
- high gravimetric and volumetric power density
- only connected to the starter
- located in the engine compartment close to the starter

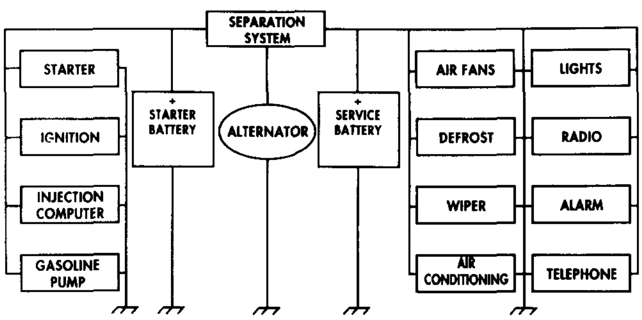

Fig. 2. Dual electrical architecture.

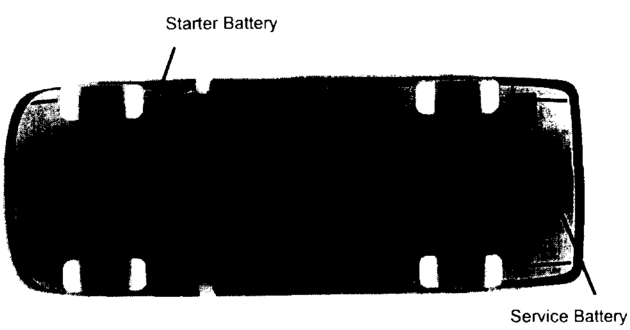

Fig. 3. Dual electrical architecture in car: battery location.

2.1.2. Service battery
- located in the boot or in the passenger compartment
- directly connected to car electrical equipment
- good ability for cycling and deep discharge
- clean and safe

The two batteries are recharged by only one alternator. A separation device (diodes, relays, etc.) insulates the starter battery from all electrical equipment, other than that used for recharge.

2.2. Concept advantages

2.2.1. Starting reliability
The starter battery remains all the time in a fully-charged state. Starting is possible even if some electrical equipment (lighting, alarm, etc.) remained switched on. The likelihood of non-starting due to a flat battery is dramatically reduced.

2.2.2. Optimization of battery design
In dual-concept, the designs of the starter battery and of the service battery can be optimized according to their use. The optimization of battery design and sizing allows reduction of the total mass of car batteries. This optimization can be improved by adjustment of starter, alternator and harness.

2.2.3. Improvement of battery location in the car
The following advantages are to be gained with the dual-concept:
- decrease of battery volume in engine compartment
- possibility of location in engine compartment of high-power batteries, thus allowing starting of large diesel engines
- it is easier to put in a car, i.e., two smaller batteries rather than one large one

2.2.4. Improvement of starting function
Battery location near the starter allows reduction in length of power cables and, therefore, in the voltage drop during starting operation. On the other hand, the possibility of supplying separately, with the service battery, the engine electrical equipment (ignition, injection for petrol engine and preheating for diesel engine) also allows improvement of the starting function.

2.2.5. Adjustment between battery range and car range
With the dual-concept, the size of the starter battery can be defined according to the engine type, while the size of the service battery is adapted to the car equipment level.

2.2.6. Improvement of electrical supply for electronic systems
The service part of a dual electrical architecture is not concerned by the voltage drop during starting operation. This allows improvement in the design and

the operating conditions of electronic equipment connected to this circuit (computers).

2.2.7. Improvement of mass distribution in car

The separation of the battery into two parts gives a better mass distribution between the front and the rear parts of cars.

2.2.8. Improvement of robustness of the car electrical system

Due to the adapted design of the service battery – to cycling and deep discharge – the electrical system of the car is more able to withstand heavy-duty conditions.

3. The dual starter battery

3.1. Battery requirements

The dual-concept has forced the consideration of new specifications for the proposed starter batteries. These specifications are different to those for current automotive batteries. In order to determine these new specifications, analyses of the operating conditions of starter batteries have been carried out in laboratories as well as in cars. The starting operation has also been studied in a car and in a cold chamber. Comparisons with the behaviour of current starter batteries in various states-of-charge have been made.

From these analyses the main requirements that the battery has to fulfill are as follows.

- Ability to deliver sufficient power during the cranking operation according to the engine size and type (petrol or diesel) and cranking conditions (temperature, etc.). For the determination of the cold cranking intensity the new European Norm (EN 60 095-1) has been selected (terminal voltage after 10 s greater than 7.5 V during discharge at −18 °C). But due to the fact than the battery is operating all the time in a fully-charged state, the cold cranking duration can be reduced.
- Reduced capacity because there is no need to start the engine in a low state-of-charge.
- Low weight.
- Low volume.
- Ability to operate in overcharge conditions (the battery is discharged during only a few seconds when the starter is operating and it is charged all the time when the engine is running).
- Ability to operate in the high-temperature conditions which are those of the engine compartment of modern cars.
- Neither a cycling ability nor a deep-discharge ability is requested.

3.2. Battery design

The authors' company (CEAC) has developed optimized flooded lead–calcium batteries. This design appears to be the most able to fulfill the above requirements. The main component features of this range of starter batteries are as follows.

3.2.1. Thin plates and grids

The increase of the cranking power requires an increase of the active surface of the plate group. This can be achieved by increasing the number of plates for each cell, i.e., the use of thin plates and grids. For automotive batteries, plates of about 1 mm thickness have been chosen. The manufacturing of these plates and grids at a high quality level requires a continuous process. The expanded metal process is able to produce such plates in a satisfactory way. Grid designs have also been optimized in order to reduce the voltage drop during cranking operation.

3.2.2. Alloys

The alloys chosen for this generation of batteries are optimized lead–calcium–tin alloys. The advantages of this type of alloy are: (i) compatibility with the rolled expanded metal process; (ii) low overcharge currents and low water consumption, even under high-temperature conditions; (iii) good corrosion behaviour in open circuit or overcharge conditions (optimized positive alloy).

3.2.3. Electrolyte

The batteries are designed with large electrolyte reserve in order to operate as long as possible at the high-temperature level of the engine compartments.

3.2.4. Separators

The separator type chosen for this range of starter batteries is the microporous polyethylene envelope. This separator is well adapted to the requirement of this product and has the following advantages.

- It is available in low thickness (less than 1 mm); this allows an increase in the number of plates per cell and a reduction in the ohmic resistance between plates.
- It is wrappable; an envelope design is absolutely necessary to ensure a high quality level, especially with very low thickness.
- It has a low ionic resistance, good mechanical properties, and good chemical resistance even at high temperature.

3.2.5. Cell connectors

The main features of a cell connector are a low voltage drop and a good mechanical resistance. It is possible to optimize the voltage-drop/lead-weight ratio with the help of a relatively simple mathematical model. This optimization is mainly important for very high cranking intensities.

3.2.6. Battery architecture

The smaller petrol engines require low cranking intensities in the range 300–400 A. For this type of intensity, it is interesting to adapt the battery design by reducing the height of the plates and of the battery. This design enables a sufficient number of plates to be kept in the group and avoids an 'end plate effect' on the power by weight ratio.

3.3. Cranking power

Evaluations of total battery weight in the car have given rise to targets for the gravimetric and volumetric cranking power of the dual starter battery. With these targets, a reduction of the battery weight can be envisaged with the dual architecture.

The values of these targets are:

- gravimetric cranking power >50 A kg^{-1} (increase of 35–65% versus current original-equipment starter batteries)
- volumetric cranking power >90 A l^{-1} (increase of 30–60% versus current original-equipment starter batteries)

Several batches of battery prototypes have been produced in L0, L1 and L2 cases with the design features described above. The cranking ability of these prototypes has been checked in the laboratory according to the EN specification, and also in engines and cars in a cold chamber.

Table 2 shows a performance comparison, in terms of cranking power, between an L0 dual starter battery and an L3 traditional automotive battery. It appears that the dual starter battery has power-by-weight and power-by-volume ratios that are 40% greater than those of traditional batteries.

Fig. 4 shows a typical power curve network for an L0 type dual starter battery (temperature range from −18 to +40 °C). This curve network shows the low

Table 2
Characteristic and performance comparison between traditional and dual starter battery

	Original equipment present design	Dual starter design
Case type	L3	L0
Dimensions: $L \times l \times h$ (mm)	278×175×190	175×175×190
C/20 capacity (Ah)	65	36
Intensity for U10s=7.5 V (A)	560	560
Weight (kg)	18.8	11.1
Massic power (A kg^{-1})	30	50
Volumic power (A l^{-1})	58	96

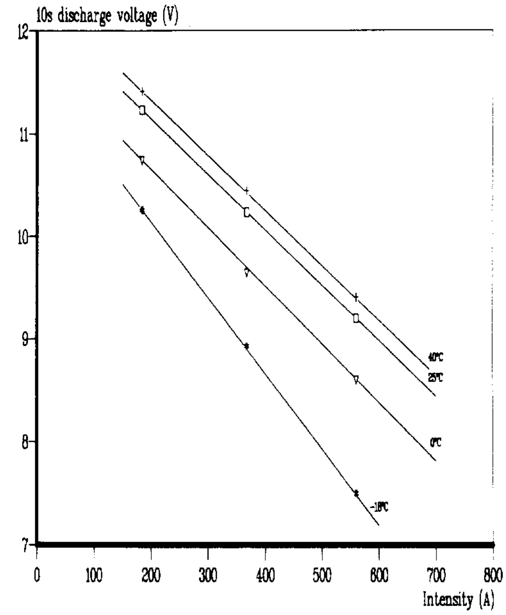

Fig. 4. Power curve network (starter battery). Voltage evolution vs. intensity and temperature (dual starter battery type=L0 560A).

internal-resistance of this type of battery. With the features described above, a complete starter battery range can be designed for cold-cranking currents from 300 A (small case, low L0 type, 175×175×150 mm) to 1000 A (L3 type, 278×175×190 mm).

With this battery range, it is possible to start any type of petrol or diesel engine used on passenger cars.

3.4. Overcharge and storage ability

In order to evaluate the life expectancy of the dual starter battery, CEAC has developed a special test. This endurance test is based on the analysis of the causes of battery ageing. Due to its particular operating conditions, the starter battery has two main causes of ageing; namely: (i) overcharge when the engine is running (possibly in high temperature conditions); (ii) standby periods at open-circuit voltage at high temperature after driving.

The endurance test is divided into units. Each unit consists of:

- a 2 week overcharge period at 40 °C and 14.8 V
- a 2 week period at open-circuit voltage at 40 °C
- a cold cranking test at −18 °C

The test is run until cold-cranking performance cannot be met.

An overcharge of a total duration of 2000 h (6 units) is estimated to be equivalent to a 4 year lifetime in a car for an average use of the vehicle.

Fig. 5 shows the behaviour of an L0 dual starter battery submitted to this kind of test. It appears that after 2000 h overcharge, the cold-cranking ability of the battery is still satisfactory. During the test, the battery water loss was less than the electrolyte reserve.

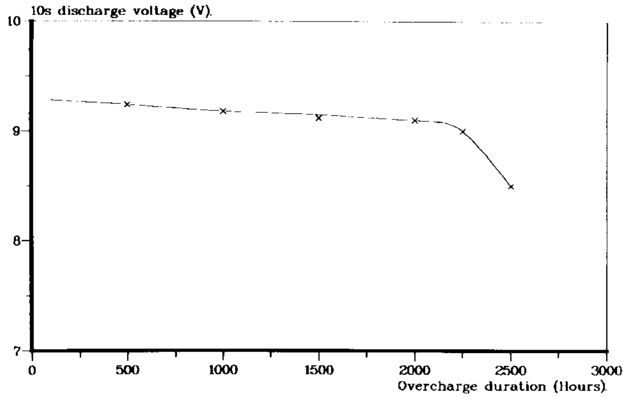

Fig. 5. Overcharge and storage life test. Cold-cranking performance vs. overcharge duration.

4. The dual service battery

4.1. Battery requirements

The function of the dual service battery is to supply the car electrical equipment when the alternator is not able to deliver sufficient electrical energy or when the engine is stopped. As with the starter battery, the service battery of the dual architecture has special requirements that are different from those of current automotive batteries. These requirements have been defined from the analysis of the operating conditions and from results of test evaluations.

The main specifications for the service battery are as follows.

- Capacity adapted to the electrical equipment level of the car, the autonomy of key-off equipment being one of the main parameters to take into account for the capacity sizing. It is important to notice that the service battery capacity can be significantly lower than that of a current automotive battery because there is no need for keeping an energy reserve to start the engine.
- Cycling ability even at low states-of-charge.
- Ability to be stored in a low state-of-charge.
- Weight as low as possible (Ah kg^{-1} target).
- Reduced volume with shape adapted to the location in the car.
- Good charge acceptance.
- Ability to supply high current (50–100 A) for a few seconds (for special equipment such as ABS pump, electrical steering, etc.).
- Due to its location at the rear of the car (passenger compartment or boot), the battery has to be clean (no acid spillage, no gas emission, etc.), and maintenance free.

4.2. Battery design

In order to comply with the above requirements of the dual service battery, CEAC has developed new types of batteries.

4.2.1. Battery technology

A sealed battery with gas recombination (starved or gelled electrolyte) has been selected because it appears to be the most suitable for the service applications. The main reasons for this choice are: (i) due to the sealed design, this kind of battery is totally maintenance free without acid spillage or gas emission; (ii) due to cell design, the cycling ability of sealed batteries is very good.

The service battery design is derived from that of small sealed batteries used in stationary applications, and has either a starved- or a gelled-electrolyte construction.

4.2.2. Battery optimization

An optimization of the service battery has been carried out to increase the energy/weight ratio. A target of 3.5 Ah kg^{-1} (42 Wh kg^{-1} *C*/20 rate) has been estimated as an acceptable level to reach the project objectives in terms of total battery weight in a car with dual architecture. The improvement of the charge acceptance was also taken into account. The parameters of component design concerned by this optimization are (starved and gelled batteries):

- grid and plate thickness (thinner than stationary batteries)
- number of plates (more than stationary batteries)
- grid weight
- grid design

Lead–calcium alloys are used for both technologies.

4.3. Performances of prototypes

A study of energy needs for car electrical equipment gave an estimation of 25–45 Ah for the service capacity. Several batches of battery prototypes have been assembled in the starved- and gelled-electrolyte design with the features described above.

4.3.1. Specific capacity

Table 3 shows the performances of an LB1/40 Ah battery. It appears that the target of 3.5 Ah kg^{-1} can be reached with this battery design.

Table 3
Characteristics and performances of a dual service battery

	Dual service battery
Case type	LB1
Dimensions: $L \times l \times H$ (mm)	207×175×175
C/20 capacity (Ah)	40
Weight (kg)	11.4
Massic capacity (Ah kg^{-1})	3.5
Volumic capacity (Ah l^{-1})	6.8

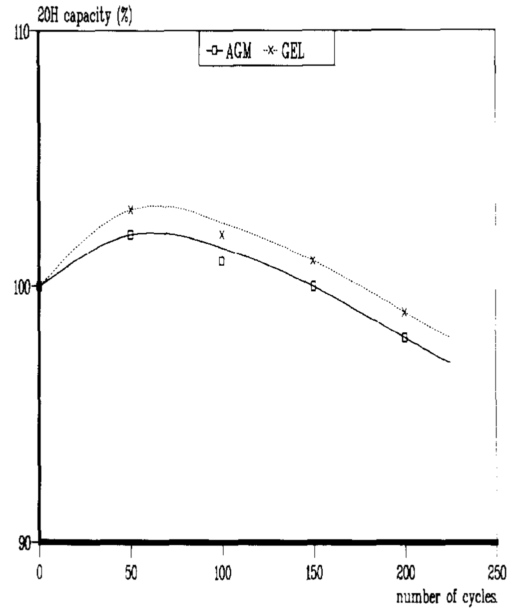

Fig. 6. Cycle life test (service battery). Capacity evolution vs. cycling time.

4.3.2. Cycling lifetime

In order to determine the life expectancy of the service battery, a cycling test has been defined, based on the following assumptions:

(i) there is no significant cycling when the engine is running (if the alternator size is well adapted);

(ii) the main cycling is due to key-off equipment when the engine is stopped.

Assuming a permanent current of 50 mA and a 22 h per day non-driving period, the cumulated discharged capacity is 400 Ah per year. Over a 5 year period, the cumulated discharged capacity is 2000 Ah, this means 50 times the battery capacity. Based on a permanent current of 100 mA, the cumulated discharged capacity over a 5 year period is 100 times the battery capacity.

From this analysis, service battery prototypes were submitted to the following test conditions:

(i) 50% depth-of-discharge cycle (at $C/5$ rate);

(ii) charge at a constant voltage of 14 V;

(iii) control of $C/20$ capacity;

(iv) requirement >200 cycles.

Fig. 6 shows that the gelled-electrolyte and starved-electrolyte (AGM) batteries reach the target of 200 cycles (100 times the capacity) without any decrease in the $C/20$ capacity.

4.3.3. Storage in discharged state

Gelled-electrolyte and AGM service batteries were kept under storage in a discharged state. This test consists of a 7 day discharge across a 10 Ω resistor, followed by a recharge and a capacity control. The two types of battery could withstand this test without any damage.

5. Dual electrical architecture

5.1. Main features

As described previously, the dual electrical architecture consists of a starter battery, a service battery, an alternator (with regulator), and a separation device. Since the main interest of the dual-concept is improvement in the starting reliability, the architecture must be designed to keep the starter battery in a fully-charged state. This is the function of the separation device that has to avoid the discharge of the starter battery (for instance by key-off electrical components) by insulating it when the engine is stopped.

But, on the other hand, the system has to ensure a satisfactory recharge of both batteries. This target has to take into account the following constraints:

(i) the use of only one alterator;

(ii) the existence of a separation device;

(iii) the different operating conditions for both batteries, i.e.,

- the starter battery always in a high state-of-charge, working at high temperature, in the engine compartment, with short cables between battery and alternator
- the service battery in various states-of-charge, requiring quick recharge, working at the temperature of the passenger compartment or of the boot, with long cables between battery and alternator

The difficulty of the charge circuit design is to ensure service battery charge in the best conditions while avoiding starter battery overcharge. Obviously, the separation device has a major rôle in the charge balance between the two batteries. The separation device can be either a passive type (diode) or an active type (relay) with a monitoring system (control unit), or a combination of both. Many different architectures can be envisaged and some of them are described here as examples.

5.1.1. Passive separation device

Such a system is a set of diodes. For example, a one-diode system (the diode is between the alternator and the starter battery, see Fig. 7), or a two-diode system (one diode in the starter circuit, one diode in

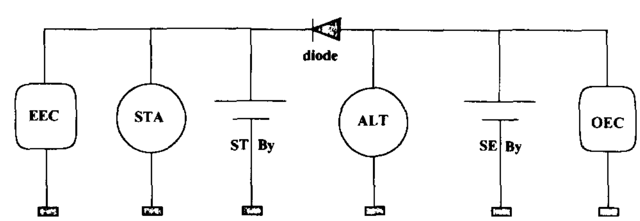

Fig. 7. Dual electrical architecture: one-diode system. ST By, starter battery; SE By, service battery; STA, electrical starter; ALT, alternator; EEC, engine electrical components; OEC, other electrical components.

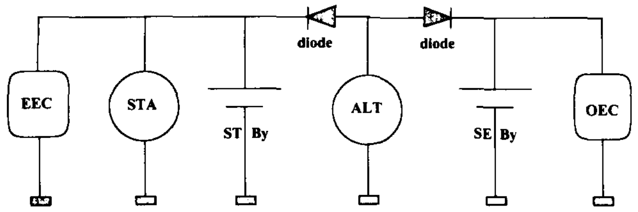

Fig. 8. Dual electrical architecture: two-diode system. ST By, starter battery; SE By, service battery; STA, electrical starter; ALT, alternator; EEC, engine electrical components; OEC, other electrical components.

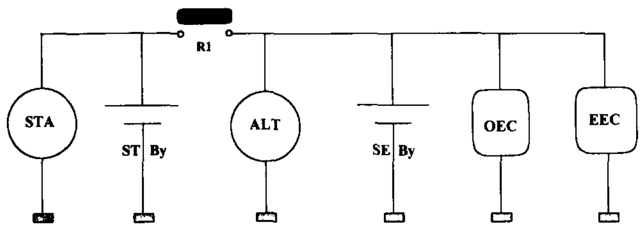

Fig. 9. Dual electrical architecture: one-relay system. ST By, starter battery; SE By, service battery; STA, electrical starter; ALT, alternator; EEC, engine electrical components; OEC, other electrical components.

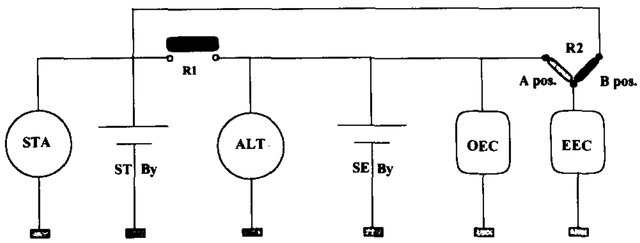

Fig. 10. Dual electrical architecture: two-relay system. ST By, starter battery; SE By, service battery; STA, electrical starter; ALT, alternator; EEC, engine electrical components; OEC, other electrical components.

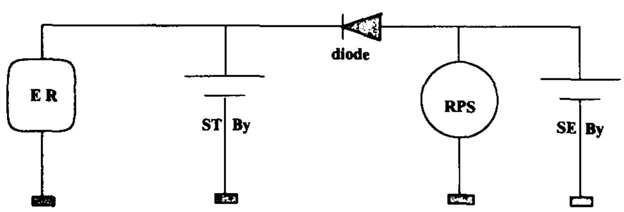

Fig. 11. Laboratory charge circuit. ST By, starter battery; SE By, service battery; RPS, regulated power supply; ER, electronic resistance.

the service circuit, see Fig. 8). The advantage of this device is its design and working simplicity.

In this system, the starter battery is not always in the highest state-of-charge before starting, because of the reversing current of the diode. In the case of a discharged service battery, a current of the order of a few tens of milliamps is supplied by the starter battery.

Another characteristic of a diode is its voltage drop, which is between 0.6 and 1.2 V for a present diode. The charge parameters (voltage, temperature compensation) have to be defined, taking into account the voltage drop of the diodes.

Table 4
State-of-charge of starter and service batteries after a 1 h charge period at room temperature

Charge voltage (V)		Initial state of charge (%)		Final state of charge (%)	
Starter	Service	Starter	Service	Starter	Service
13.2	13.8	100	0	100	55–60
13.2	13.8	50	50	70–75	75–80
13.2	13.8	50	0	70–75	55–60
13.6	14.2	100	0	100	70–75
13.6	14.2	50	50	80–85	85–90
13.6	14.2	50	0	80–85	70–75

Table 5
Weight comparison in dual and present electrical architecture

Engine type	Present architecture	Dual architecture		
		Starter	Service	Total weight
Gasoline	480 A	430 A		
engine	65 Ah		30 Ah	
	18.2 Kg	8.6 kg	8.6 kg	17.2 kg
Diesel	740 A	710 A		
engine	88 Ah		30 Ah	
	25.4 kg	14.2 kg	8.6 kg	22.8 kg

5.1.2. Active separation device

Such a system is a set of relays monitored by a control unit. Several relay dual architectures exist. Figs. 9 and 10 show examples with one-relay and two-relay systems.

The advantage of the relay system is the ability to monitor relay operating (opening, closing), from information on vehicle situation and on battery state-of-charge. Another advantage of the relay system is to improve starting reliability by maintaining the starter battery in a full state-of-charge. This is possible by connecting engine electrical components to the service battery. With this solution, starting reliability is also improved by a decrease of intensity supplied by the starter battery. The intensity supplied to the engine electrical components comes from the service battery. The battery charge may be monitored by the relay system, according to the situation of the batteries (temperature battery, state-of-charge) and of the circuit (electrical balance).

5.1.3. A solution for electrically heated catalysts

Dual electrical architecture is a well adapted concept to ensure the energy supply of electrically heated catalysts (EHCs) for internal-combustion engined cars.

The use of an optimized power/energy battery dedicated to the EHC function (2–4 kW during a few tens of seconds) and to the starting function (1.5–5 kW during a few seconds) leads to a better trade-off – in terms of battery weight, battery location and quality of on-board voltage – than other electrical architectures (e.g., only one battery or one battery only dedicated to the EHC). Nevertheless, some requirements of this battery are different from those of the starter battery described previously. In particular, the cycling ability must be greater.

In this architecture, the service battery has the same functions and the same design as that in a car without an EHC, and it is designed according to the electrical equipment level.

5.1.4. Compatibility with on-board voltage increase

The dual-concept is totally compatible with an on-board voltage increase (24 or 48 V) but, in this case, battery optimization has to be reviewed.

5.2. Tests on one-diode dual electrical architecture

5.2.1. Laboratory tests

Recharge tests have been carried out in the laboratory with electrical circuits that reproduce dual electrical car architecture with diodes (see Fig. 11, an example with one diode). The targets of these tests were:

(i) to determine the recharge ability of two batteries connected in parallel with a separation device;

(ii) to evaluate the impact of the charge parameters (regulation voltage and diode voltage drop) on the recharge kinetics of the starter and service batteries.

Table 4 shows the battery states-of-charge after a 1 h charge period (in the tested circuit the voltage drop of the diode is 0.6 V). It appears that the final battery state-of-charge depends significantly on the voltage regulation. With an adjustment between the diode-voltage drop and the voltage regulation, both batteries can be recharged in an acceptable way. A voltage regulation in the range 14–14.4 V is required to ensure recharge of the service battery without overcharge of the starter battery.

5.2.2. Car tests

The one-diode electrical architecture has also been studied in a vehicle. The car was equipped with an L0 starter battery (located in the engine compartment) and an LB1 service battery (located in the boot). The starter and service battery designs were of the types described previously. The diode located between the alternator and the starter battery had a voltage drop of 0.6 V.

The main results are as follows:

(i) the car operates well with the dual architecture;

(ii) it is possible to start with a flat service battery;

(iii) with an adjustment between the diode voltage-drop and the voltage regulation (including thermal compensation), the service battery can be recharged without starter battery overcharge.

Electrical balance and thermic studies have shown a satisfactory behaviour of both batteries.

5.3. Example of car equipment with dual architecture

From the designs for optimized starter and service battery, some evaluations of car electrical equipment have been carried out in order to make comparisons, particularly about weight, between traditional and dual architectures. This study has been performed for both petrol and diesel cars.

Table 5 shows that it is possible to reduce the total battery weight in a dual architecture. This weight reduction can be improved by an adjustment of starter and alternator sizes. The dual-concept appears to be a way to reduce the weight of car electrical equipment and, thereby, address a permanent concern of car manufacturers.

6. Conclusions

The dual-concept appears to be the best answer to problems with present starter batteries. This concept particularly allows a huge improvement in starting function reliability and it is very well adapted to meet user requirements in future top-of-the-line cars. During this study, the feasibility of the dual architecture has been proved both by laboratory tests and by experiments in cars.

New battery designs designed to satisfy the dual-concept have been developed and tested. These optimized starter and service batteries are able to meet the new specifications that result from separation of the battery functions.

On the basis of the dual-concept, many car electrical architectures can be envisaged and some developments remain to be achieved, particularly concerning the separation and monitoring system between the starter and service circuits. The dual-concept is totally compatible with other possible evolutions of the car electrical equipment, such as on-board voltage increase and electrically heated catalysts. The dual-concept should reach industrial development in the near future.