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Intelligent automotive battery systems*

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Abstract

A single power-supply battery is incompatible with modern vehicles. A one-combination 12 cell/12 V battery, developed by Power Beat International Limited (PBIL), is described. The battery is designed to be a 'drop in' replacement for existing batteries. The cell structures, however, are designed according to load function, i.e., high-current shallow-discharge cycles and low-current deep-discharge cycles. The preferred energy discharge management logic and integration into the power distribution network of the vehicle to provide safe user-friendly usage is described. The system is designed to operate transparent to the vehicle user. The integrity of the volatile high-current cells is maintained by temperature-sensitive voltage control and discharge management. The deep-cycle cells can be fully utilized without affecting startability under extreme conditions. Electric energy management synchronization with engine starting will provide at least 6% overall reduction in hydrocarbon emissions using an intelligent on-board power-supply technology developed by PBIL.

Introduction

This paper contains details of the Discharge Management System (DMS)™ technology of Power Beat International Limited (PBIL), and includes a description of the various alternative methods of application.

An optimized one-combination, multiple-discharge characteristic 12 cell/12 V battery is also described for application as original equipment. (The description includes obtainable electrical capacities and weights).

Summary of the discharge management system

A multiple-discharge characteristic battery is ideally suited to a discharge management system. The 'Powerbeat' system is designed to operate automatically and is synchronized to the vehicle and vehicle users' needs.

Objectives of the Discharge Management System (DMS)

DMS is designed to provide the following important functions:

- prevent deep discharge of the volatile cranking battery or cells
- ensure correct charging of the high current cranking battery or cells when the engine is running

*Technology explained in this document is subject to Patents that have been issued or are pending in the USA and other countries.

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- automatically switch current to the vehicle ignition system in emergency situations so that the vehicle can be started, no matter how long or how severe the drain on the low-current cells has been
- ensure stable voltage supply to the engine ignition/management system and fuel pumps while the engine is being cranked
- prevent deficit charging of the cranking cells
- prevent overcharge of the cranking cells
- reduce hydrocarbon emissions created by engine starting

Methods of application

There are four alternative methods of application. These are:
(i) movement sensor (this is primarily designed for the replacement battery market);
(ii) integrated triggering (an inexpensive application for original equipment);
(iii) total integration and energy management scheme;
(iv) various combinations of the above three methods.

Summary of the optimized one-combination battery

Discharge management is ideally suited to a multiple-discharge characteristic, on-board, power supply. There can be either two separate batteries, or a one-combination binary battery that has at least two different discharge characteristics, i.e., one capable of high discharge for starting and the other capable of a lower discharge rate for vehicle auxiliary power consumers. The lower discharge rate battery, or cells, are deep-cycle types and are designed specifically for motor vehicle use.

Objectives of the one-combination battery

The one-combination battery is designed to provide the following important features:
- multiple discharge characteristics that are compatible with a vehicle's actual on-board electrical power requirements; this specifically creates an operational power supply
- optimized low weight for maximum power density and minimum vehicle weight
- lowest possible cost
- extended life
- ease of installation and accessibility in a vehicle
- parts inventory compatibility

Brief overview of a conventional vehicle power distribution scheme including power supply, alternator and starter motor

The standard power distribution system indicated by Fig. 1 shows that all power consumers share a common connection at the positive terminal of the conventional battery. The dominating design objective of a conventional battery is to provide sufficient power for cranking.

Overview of binary on-board power supply

The dividing of the power supply harness between two cell groups that are designed according to load function provides a more compatible and safe on-board power supply. Figure 2 gives an indication of a simplified power distribution system that utilizes an optimized 'binary' battery.

In Fig. 2, 1B an optimized 12 cell/12 V battery (European version), with an integrated movement sensor DMS for the aftermarket. The low-current load lines (via

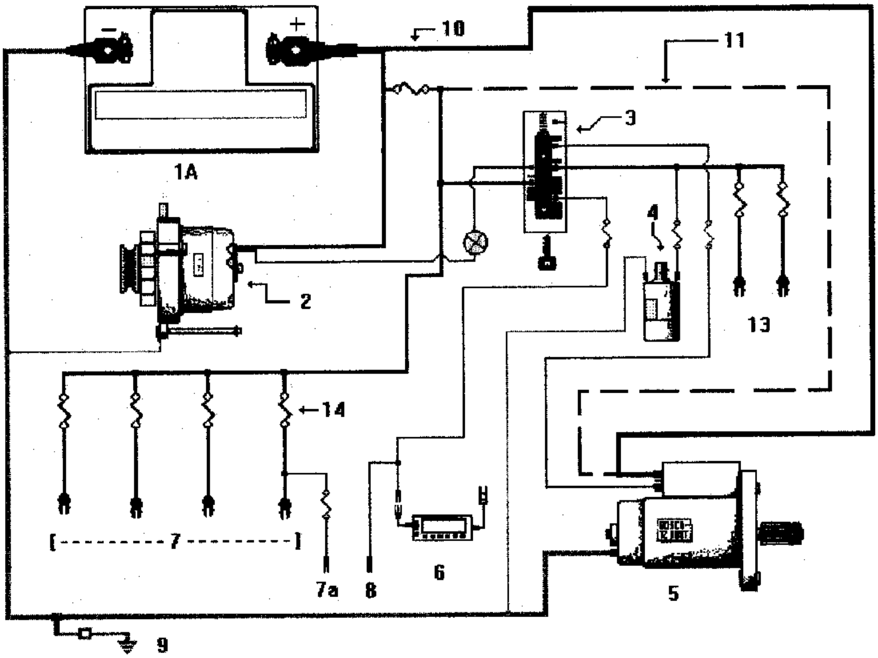

Fig. 1. Conventional battery and power distribution scheme. This simplified schematic shows: (1A) a conventional battery; (2) a typical alternator; (3) a key switch; (4) ignition; (5) a typical starter motor with built-in solenoid; (6) a power consumer, 'hot' when the key turned to the first auxiliary position; (7) multiple power consumer supply lines, hot at all times; (7a) ultra-low current consumer lines, hot at all times; (8) low-current consumer lines, hot when key is turned to the first auxiliary position; (9) the negative earth connection to the vehicle body and engine; (10) the low-resistance main power line to the starter motor, hot at all times; (11) an alternative auxiliary power supply line used for some older designs makes a connection at the starter solenoid; (13) auxiliary consumer lines, hot when key turned to ignition; (14) a fuse.

DMS 18) are divided away from the main power supply line 10 to the starter 5. Figure 2 also indicates an alternative connection (via 18) between the key switch 3 and the main power supply to the starter or main positive terminal of the battery; this alternative connection is not available for the aftermarket, but does indicate a simple alternative triggering method for resetting of the DMS 18. Line 12 also includes an automatic resetting thermal overload switch.

Two-battery system

A two-battery system that utilizes either a movement sensor, a key-activated DMS, or a integrated power distribution system can be adopted. A possible advantage of a two-battery system is the placement of the batteries in different locations. Disadvantages include higher cost, higher weight, parts inventory incompatibility, and recharge imbalance.

Figure 3 shows a high performance starter battery, 1c, of minimum size, say 400 CCA (under the SAE standard) and an auxiliary deep-cycle type battery, 1d, of say 34 A h. The total minimum weight of this system would be between 21 to 24 kg for a total capacity of ~68 A h.

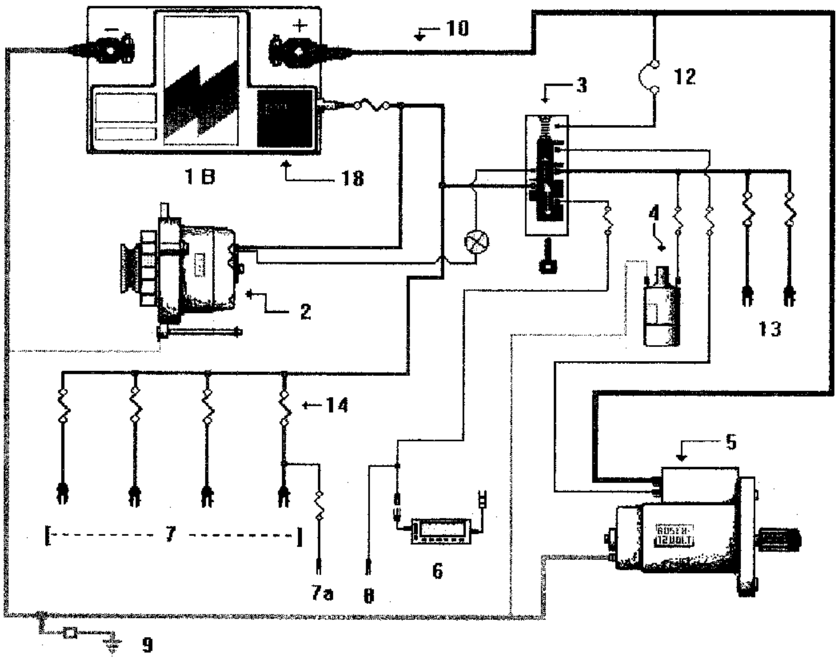

Fig. 2. Binary battery and compatible power distribution scheme for aftermarket application.

Integrated triggering for original equipment application

A movement sensor DMS is not needed for original equipment application of a binary on-board power supply. Replacement of the operational amplifier by a 'wired-in' or integrated triggering system is a more suitable arrangement. An ideal switching logic is easily achieved by the wired-in system.

Table 1 outlines an ideal programme for switching between the two positive terminals of a high-current, shallow discharge, group of cells and a low-current, deep-cycle, group of cells. This programme is accomplished by application of a simple key triggering scheme. Note: an additional function incorporated into some DMS units is a time delay, related to the discharge state of the auxiliary cells, to ensure recharge of the auxiliary cells prior to starting. This delay ensures optimum starting subsequent to deep discharge of the auxiliary cells, and is between 0 and 20 s. It can be implemented electronically or in other ways such as by triggering-off door opening and closing, as well as by the ignition key switch.

The simple key or door-activated DMS utilizes an electromagnetic switch that is ideally suited for parallel charging of battery cells. The switch is able to be activated according to the programme of Table 1. A solid-state switch is not suited to this function because of a voltage drop of at least 0.5 V, as well as other disadvantages that include cost and the need for overcurrent protection. The operation of the switch under the scheme described and shown in Fig. 4 is transparent to the vehicle user. The switch is operated according to signals supplied either by turning of the key to the start position or by opening and shutting of the door, pressure, or other methods associated with normal driver orientation.

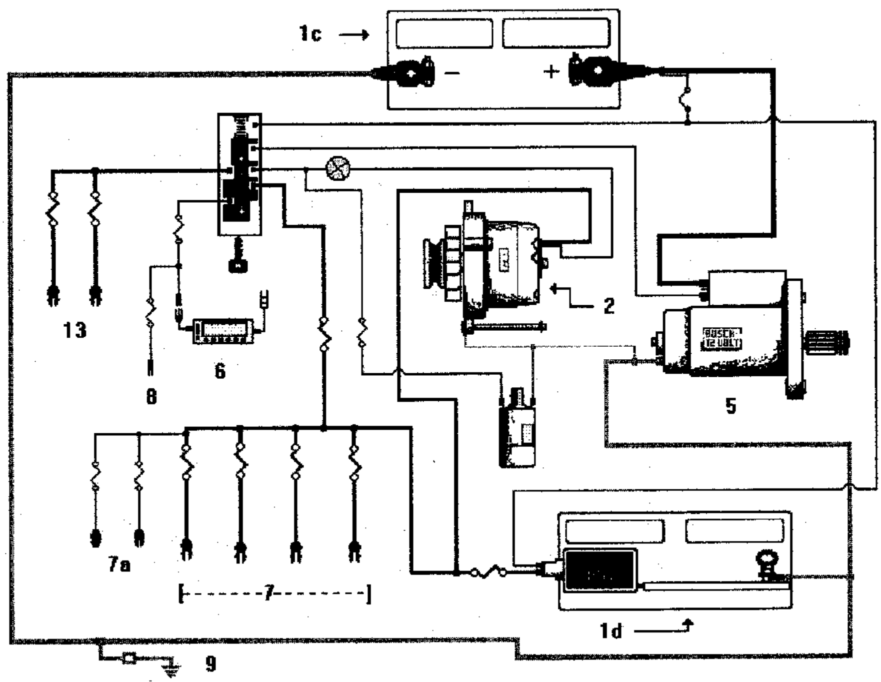

Fig. 3. Alternative two-battery system utilizing DMS.

TABLE 1

An ideal switch management programme for original equipment DMS application

Vehicle condition	Relay	
	'Closed'	'Open'
Parked–engine not running		×
Engine running–voltage at auxiliary terminal >12.5 V	×	
Engine running–voltage at auxiliary terminal <13 V		×
Engine stopped–voltage at auxiliary terminal more > ~11 V and engine about to be cranked by the ignition key being turned to start position		×
Engine about to be cranked by key being turned to start position, voltage at auxiliary terminal < ~11 V	×	
Engine being cranked and cranking terminal ~2 V below auxiliary terminal		×
Ambient temperature around battery +70 °C		×

In Fig. 4, 18 is the DMS controller which should be integrated into the battery cover or lid. The DMS controller must activate switch 18a in accordance with the programme of Table 1. The terminal 18b is connected to the deep-cycle cells and the connector 18h is connected to the auxiliary power harness and vehicle alternator. When the key is turned to the start position, or the vehicle door is opened and closed,

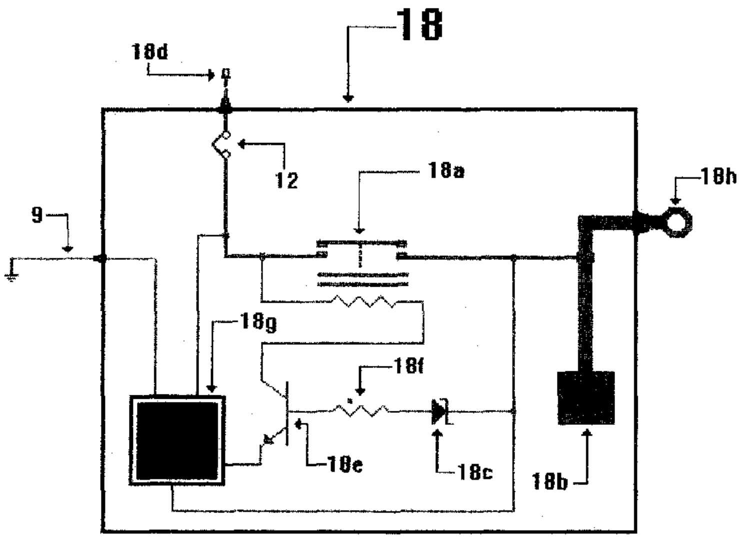

Fig. 4. Wired-in DMS for original equipment application.

a voltage comparator 18g will switch off the transistor 18e, if the voltage at both terminal connectors 18h and 18d is above 12.2 V, for example only. If the voltage at terminal connector 18h is lower than 10.5 V, the voltage comparator 18g will allow a switch to earth at 9. Consequently, following the vehicle being started, the voltage from the vehicle alternator should be in excess of 12.5 V, therefore the Zener diode 18c will allow current to pass to transistor 18e through the voltage comparator to earth. This will energize the coil of switch 18a that draws its power from the cranking terminal via connector 18d. Switch 18a will therefore close and remain closed whilst the voltage is higher than 12.5 V because the alternator is supplying sufficient current to switch both the main cranking terminal and the auxiliary terminal 18b into electrical parallel. The thermal resistor 18f will protect transistor 18e from overvoltage and will increase in resistance as the ambient temperature rises around the battery. Thermal resistor 18f will cause the transistor 18e to open if the temperature rises above 70 °C; this prevents overcharging of the volatile cranking cells at high temperatures.

Totally-integrated energy management scheme for original equipment application

A totally-integrated energy management scheme requires an optimized battery of rapid discharge and deep-cycle capability being integrated with the power distribution system as the principal on-board power system component.

Figure 5 is a simplified power distribution scheme showing an energy management switch 15. A recommended power consumer scheme is included and a battery 1B has an integrated DMS 18.

Total integration and energy management provide the major advantages of minimum cost and weight. Installation of a single energy management switch to control the use of the stored energy is ideally suited to a binary or two-battery system.

The effect of the integrated energy management switch 15 is clearly demonstrated in Fig. 6. This shows the auxiliary supply cell terminal voltage climbs after 25 min

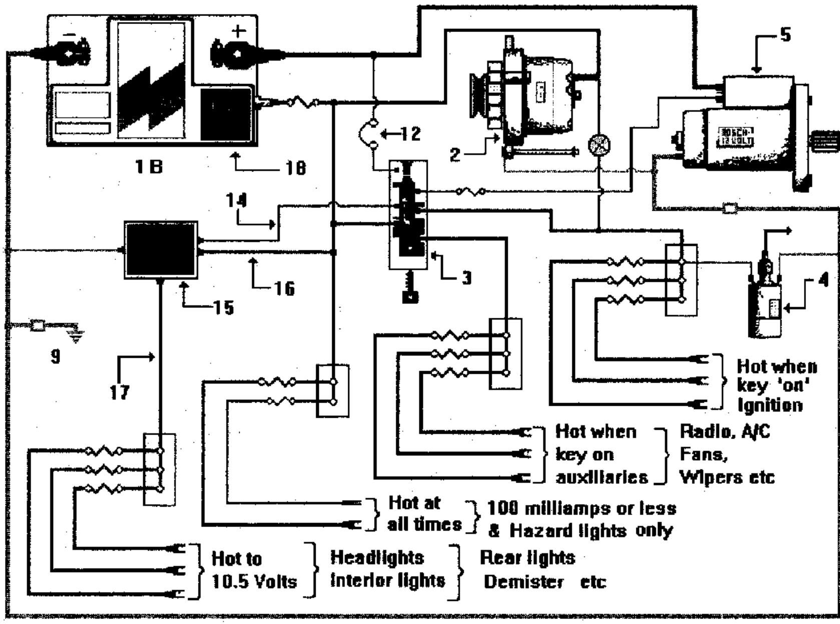

Fig. 5. Integrated energy management and power distribution.

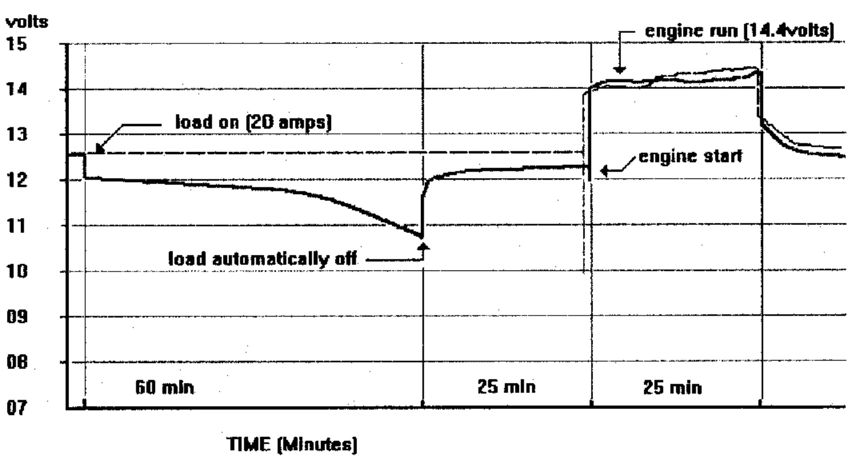

Fig. 6. Effect of automatic load shedding: (——) auxiliary volts, and (– – –) cranking volts.

from 10.5 V following automatic removal of a load of approximately 20 A via switch 15. It can be seen that the voltage at the cranking terminal remains stable at between 12 to 12.5 V during this period. The cranking voltage drops during starting, but the combination of the energy management switch and DMS 18 prevents this from affecting the voltage supplied to the engine management. This results in minimal voltage losses to the latter during starting. The voltages after engine starting follow a generally parallel pattern while the vehicle is being driven and the alternator is supplying ideally 14.4 V.

Figure 7 shows the specific effect of the stable voltage that is achieved by the energy management switch 15 in combination with DMS 18, when used with a one-combination, 12-cell, battery system. Prolonged discharge of the deep-cycle auxiliary cells is automatically controlled by switch 15. Power is provided to the ignition/engine management switch via the alternative line 12 (Fig. 5) should the voltage of the auxiliary cells drop to 0.72 V, which is required to activate the DMS by key triggering.

This situation may arise if ultra-low current loads have been operating for more than, say, 20 days without the engine running. The period of time depends on temperature and on the size or weight of the deep-cycle cells. In any case, the vehicle can be started readily either during, or even long after, this time by the normal starting procedure with no other driver intervention when this system is installed (Fig. 8).

Detailed description of one-combination battery

Emission reductions are possible with Powerbeat technology because when the battery and DMS are correctly integrated into a new vehicle as original equipment,

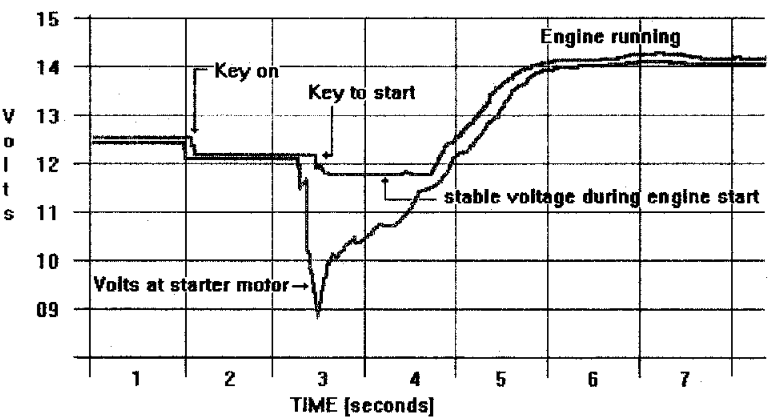

Fig. 7. Ignition volts during start (integrated DMS and energy management) and cranking volts.

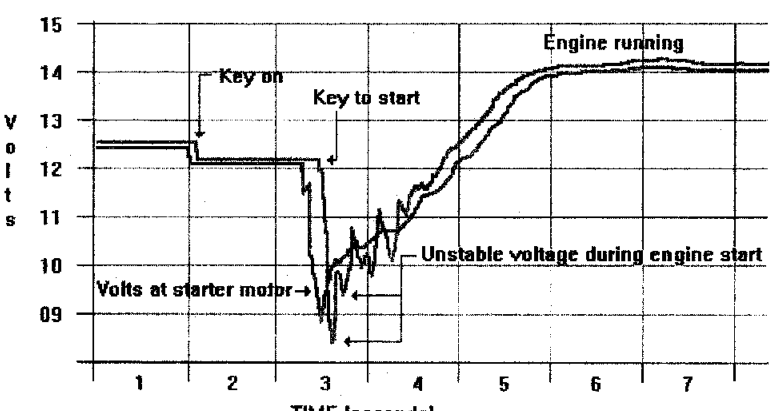

Fig. 8. Volts taken at engine management showing unstable voltage during engine starting with a conventional scheme (i.e., Fig. 1).

the engine management programme and fuel mixtures can be adjusted during engine starting, and thus make it possible for the engine to start instantaneously. The Powerbeat technology is able to supply a constant and stable voltage to the engine ignition system.

Approximately 15% of vehicle emissions are caused by unburned fuel that builds up when the engine is being started. An instantaneous start reduces the amount of unburned fuel. It is possible with Powerbeat technology for an internal combustion engine to fire on the first compression stroke even in extreme starting conditions. Such a situation is not possible with a conventional battery and power distribution system.

Because the engine will start with an integrated Powerbeat system, there can be no misfires and thus the build-up of unburned fuel is avoided. A 6% reduction in hydrocarbon emissions can be achieved with new vehicles specifically designed with DMS.

Existing automotive battery standards are incompatible with the actual on-board power requirements of a vehicle. A vehicle specifically requires a battery to have cell structures designed according to load function. An ideal replacement system is a one-combination battery.

A 12-cell, one-combination battery is able to replace the existing standard at relatively little increase in cost. The battery must be of balanced design and function. A Powerbeat optimized one-combination battery that comprises a series of six high-current discharge cells in combination with low-current, deep-cycle cells is described below.

The battery is able to meet the dimensions and replace a broad number of conventional batteries, with one size only. To achieve this, it is necessary to consider the advantages of the DMS that uses a totally integrated DMS and an automatic energy management scheme. It is possible to rationalize the weight of the battery and also increase the reliability of the battery. With these features, vehicle starting in the normal way is assured, even in the most extreme conditions.

Optimized plate structure

In considering the overall weight of the battery, it is necessary to design the electrode plates and cells according to the specific load requirements for which they are to be used. Whereas a conventional battery is a compromise between a high-current and a deep-discharge design, the plates of the cranking cells of the Powerbeat system are protected from multiple deep-discharge by the DMS. This enables the plates to be designed more effectively for high-current discharge and, therefore, it is possible to reduce safely the mass per cell whilst increasing the energy-to-weight density of these cells.

Calculations and tests indicate that a group of six high-current cells that weigh less than 7.5 kg (wet) and have a high-rate discharge capacity of ~400 A is possible. The plates can utilize a low density active-material mix, particularly at the positive plates. As the active material is essentially a semiconductor, the resulting voltage drop is significant unless a high conductive lead grid design is used more effectively. Such a system is shown in Fig. 9 whereby a plate for higher current discharge utilizes a more efficient grid design.

Figure 9 provides a description of a high-current discharge positive plate 19, with active material 19a, partly removed, grid wires 19b, a moulding 'flash' 19c, that tapers away towards the centre. The flash also contains perforations 19d that are provided for keying of the active material. The latter is applied by orifice pasting.

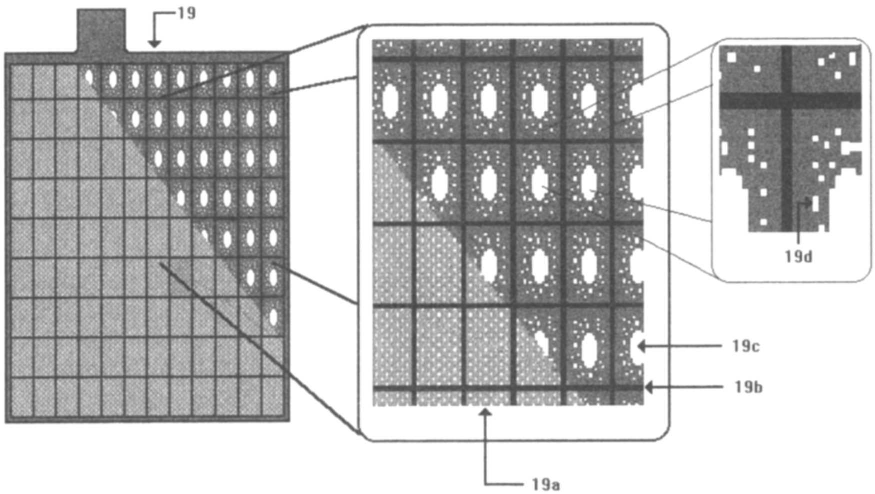

Fig. 9. Optimized high-current discharge positive plate.

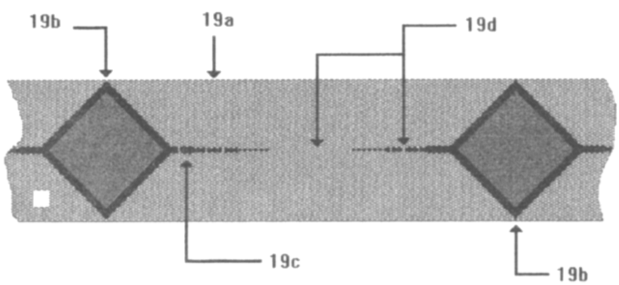

Fig. 10. Enlarged cross section of optimized rapid-discharge electrode plate.

Figure 10 is a schematic cross section of a segment of the plate. The diagram shows active material 19a, a cross section of grid wires 19b, and the lead mould flash 19c. The latter is created by mould design and the cavity allows the active material (in this case lead oxide is indicated) to be applied from both sides of the plate by orifice-pasting techniques. The active material is keyed through the perforations 19d, and the large aperture that is not covered by the flash.

High-rate discharge cells

The plate design described above reduces the resistance to rapid discharge of current by providing extra higher conductive lead to supplement the semiconductor characteristics of the lead oxide active mass. Such plates can be manufactured using conventional equipment and with a wire diameter that is less than in conventional plate designs. Ultra-low antimony, or a combination of antimony–calcium technology, is ideal for cranking cell designs of the one-combination battery. The battery can be of the sealed type.

The reduction in high-current resistance provided by this particular design can be calculated to increase effectively the high-rate discharge characteristics whilst at the same time to reduce the actual mass per cell. Because these cells are relatively volatile (that is, they are easily damaged by overcharging at high temperatures), the integrated DMS described earlier is most suited to these designs.

The high-rate discharge cells are damaged because of deep-cycle abuse or continuous charging at high temperatures. The electrode plates of the cranking section are ideally suited to polyethylene envelope separators and can be a 'non-maintenance' design. The reliability of these cells is enhanced by the protection provided by the simple DMS technology.

Deep-cycle, low-rate discharge cells

Deep-cycle technology designed to be compatible with auxiliary on-board power requirements of a motor vehicle must be capable of withstanding high temperature and prolonged abuse. The electrode plates, particularly the positive plates, should be designed to withstand the effects of multiple discharge/recharge cycles.

Charge acceptance is critical because of inconsistent charge under extreme driving conditions. The positive plates of the auxiliary cells are most effective when a folded plate technology is adopted.

Figure 11 illustrates a suitable positive plate configuration for optimized energy use by auxiliary power consumers that range from high-power consumers such as headlights through to ultra-low-current consumers such as electronic management systems. Electrolyte penetration through the centre of the structure assists electronic diffusion through the active material which is of a greater density than the active material used for the cranking plates.

The double grid arrangements are essentially the same as the grids used for the cranking section, but they have been folded and retain an electrical connection at the bottom. A cell configuration using this simple technology provides for long-life, multiple cycling and energy use compatibility.

Figure 12 shows the ideal arrangement of deep-cycle cells 20 designed for auxiliary power and load-levelling use. The outer negative plates 20a are of a thickness relative to the required use of active material. The inner negative plates 20b are balanced according to the active-material levels of the folded positive plates that are encased in glass-reinforced polyethylene envelope separators 20c.

This arrangement is ideally suited to present and future automobile designs. The cell layout of the battery is arranged for efficiency of manufacture and power discharge/recharge. There is one negative cell and two positive terminal cells.

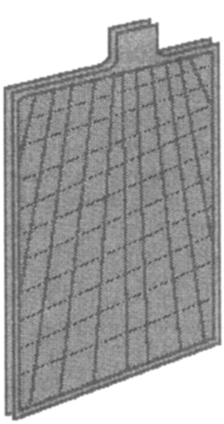

Fig. 11. A folded positive plate designed for deep-cycle use in an automobile.

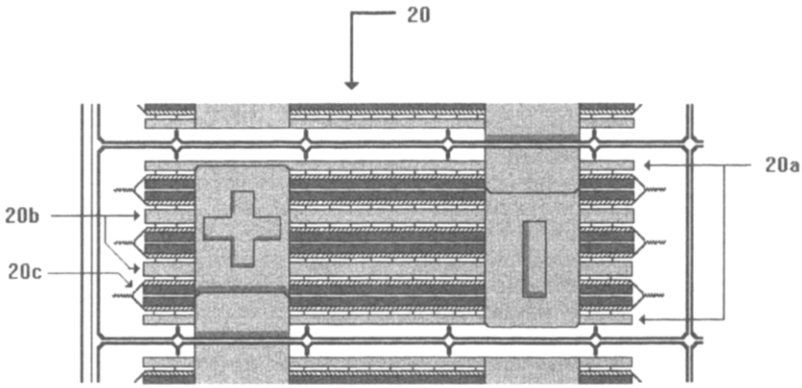

Fig. 12. A close-up view of the preferred arrangement of the deep-cycle cells.

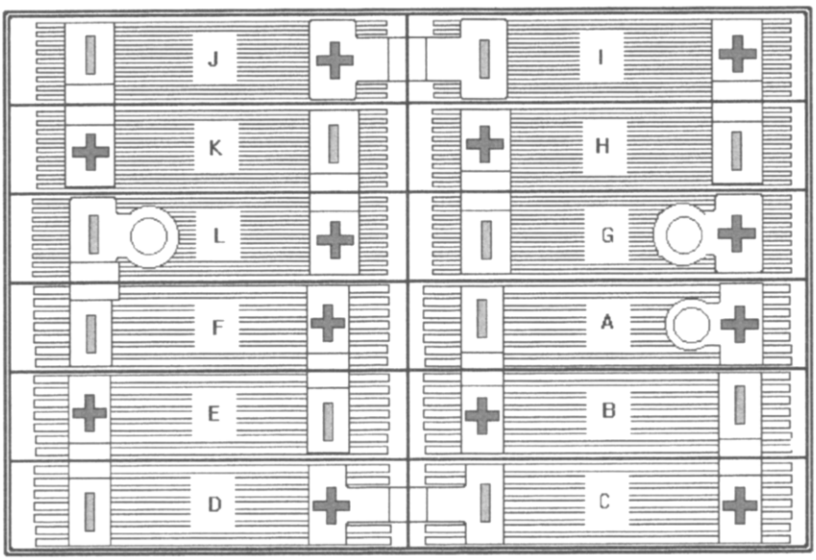

Fig. 13. Cell layout of one-combination, multiple-discharge characteristic system.

Figure 13 shows cells A–F of compatible deep-cycle design and cells G–L for higher power discharge to shallow levels. This format provides a battery of suitable dimensions and capacities for drop-in replacement of conventional automotive systems.

Figures 14 and 15 show the elevations of the preferred European 12-cell one-combination battery. Cell space above the elements should be sufficient to provide an electrolyte level that is at least 15 mm above the connector straps. Sufficient electrolyte volume will prolong the life of the cells. The auxiliary power connection to the DMS is screwed to the cover and sealed with a rubber gasket, as shown in Fig. 16.

Specifications of the European version 12-cell, one-combination design

Although multiple group sizes of conventional automotive batteries exist, the provision of a one-combination system with optimized cells that are designed according to load function will reduce the group sizes significantly.

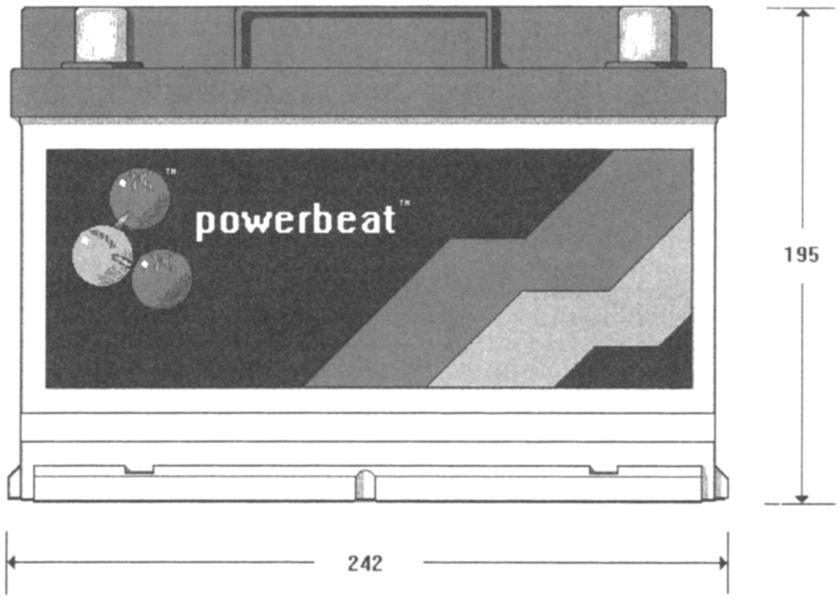

Fig. 14. Side elevation of European version of one-combination, 12-cell, automatic battery manufactured by Power Beat.

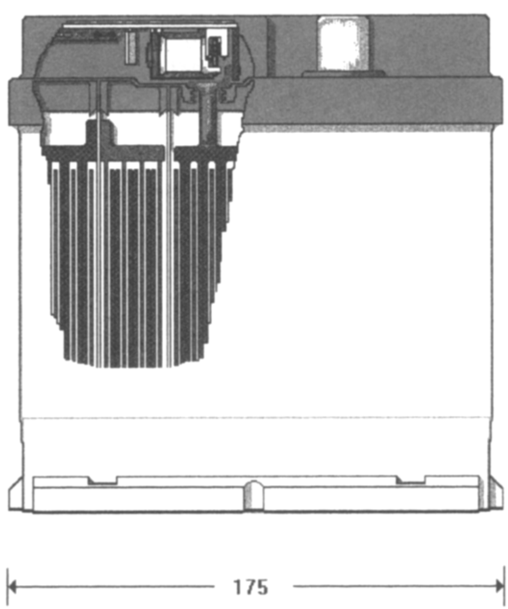

Fig. 15. Positive end elevation, European version.

The European version referred to in this paper (Table 2) will replace 90% of existing conventional group sizes for passenger cars. Two North American and Japanese versions are to replace 100% of existing group sizes for passenger cars throughout Asia, the America's and the South Pacific.

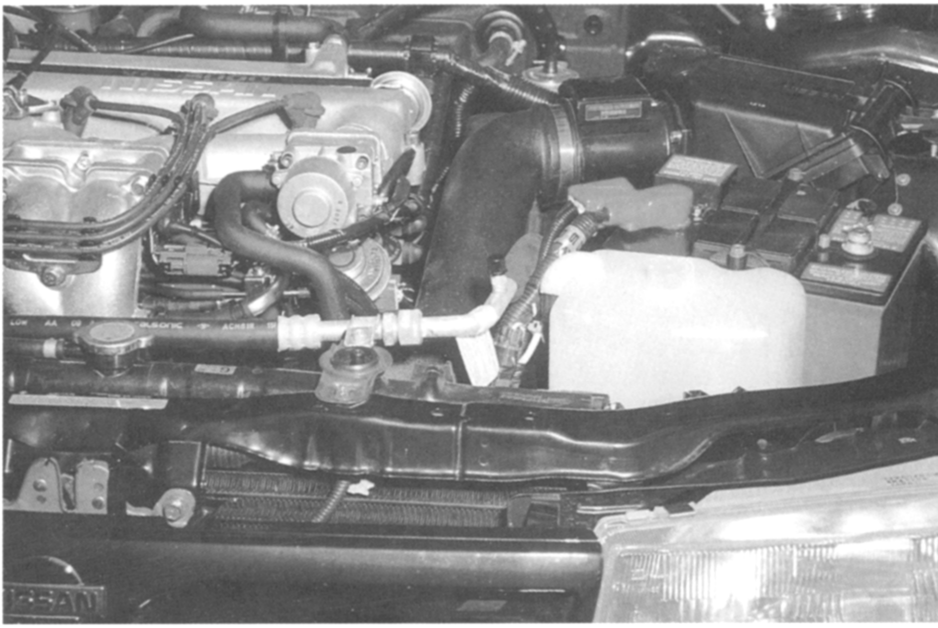

Fig. 16. The Powerbeat battery looks like a conventional battery; it is designed to be a 'drop-in' replacement for existing batteries. This is possible with modern vehicles that divide the starter motor cable from the auxiliary power harness at the battery's terminals.

Summary of binary on-board power technology advantages

Power Beat International Ltd. has designed an optimized replacement standard for existing automotive starter batteries. The Discharge Management System (DMS) includes one aftermarket and two original equipment applications. The four main advantages of the technology are as follows:

(i) Efficient starting

- vehicles will start under all conditions
- instantaneous starts will be possible with engine management CPU programme variations, injector pump variations during crank time and correct fuel-to-oxygen mixtures for start-up. This will result in lower (about 6%) overall emissions and less engine wear
- all engine starting will be automatic, regardless of the auxiliary power drain whilst the vehicle has been parked

(ii) Reduced overall vehicle weight

Conventional starter batteries have included a specified minimum reserve capacity; this capacity continues to increase in order to provide minimum starting power after an acceptable key-off load period. As the key-off loads increase, the weight of the battery must also increase, startability is still not guaranteed because of 'accidental discharge' which is the prominent cause of vehicle breakdowns. A binary system as designed by Power Beat eliminates the need for increasing battery weight. The DMS or energy management logic will provide more efficient energy use at lower weight.

TABLE 2

Specifications of the European version

Multiple discharge characteristic 12-cell/12-V automotive battery (European version)	
Dimensions	
Length (mm)	242
Width (mm)	175
Height (mm)	195
Capacity (A h, 20-h rate)	
Crank cells	32
Deep-cycle auxiliary cells	34
Combined total	66
Mass (wet) (kg)	16.2 approximately
High-rate discharge (SAE CCA)	
Crank cells	410
Deep-cycle auxiliary cells	180
Combined total	590
Plate design and cell configuration	
Crank cells	Low resistant 0.8 mm cast grids, low density active material, 9 plates per cell Calcium–antimony hybrid system
Deep-cycle cells	Folded double, low-antimony cast grids
Separators	
Crank cells	Polyethylene envelopes
Deep-cycle cells	Glass reinforced polyethylene envelopes Positive folded grids only

(iii) Cost

- high volume production of a binary battery will result in costs being comparable with conventional 6-cell batteries of equivalent electrical capacity (20-h discharge rate)
- major service cost savings are available to new vehicle manufacturers through reduced warranty and service call-outs
- power distribution cost savings are available with rationalized networking and switching
- multiplexing of the power harness is easier with constant stable voltages

(iv) Longer service life

- optimization of battery cells according to load function will increase the service life of the battery; deep-cycle technology provides up to 1200 and 175 discharge cycles at 30% and 100% DOD, respectively.
- energy management through DMS will protect volatile rapid discharge cells from deep discharge and overcharge at high temperature
- estimated service life of the Powerbeat battery and the discharge management system should be around 7 to 10 years.