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EQUIPMENT FOR TESTING AUTOMOTIVE LEAD/ACID BATTERIES UNDER SAE J240a CONDITIONS

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Summary

Battery cycling equipment has been designed and constructed to test lead/acid batteries according to the American Society of Automotive Engineers' (SAE) J240a Standard. This life test simulates automotive service where the battery operates in a voltage-regulated charging system. The CSIRO design uses a master/slave concept to reduce both construction time and cost.

Introduction

The most common usage of lead/acid batteries is in providing an electrical supply for petrol-driven vehicles. These batteries are known as automotive, starter, or SLI (SLI = starting, lighting and ignition) units. During the past few years, the automotive battery market has been transformed, first by the appearance of the "low-maintenance" type, and now by batteries that are sealed-for-life and claimed to be "maintenance free". Initially, the introduction of sealed batteries was linked with the decision of car manufacturers in the early nineteen-sixties to replace d.c.-generating dynamos with more efficient, alternator/diode-rectifier systems. Recent developments in automotive engineering have enhanced the need for sealed batteries. New vehicle designs are aimed at greater fuel economy through, for example, reduced vehicle size. This, together with space restrictions caused by the introduction of emission control equipment, has involved relocating the battery in "dead space" where regular maintenance can be both difficult and inconvenient.

The battery industry has long recognized the need for an accelerated laboratory life test to indicate how long a battery would operate in actual vehicle service. Such a test would assist in evaluating materials, manufacturing technologies, and design concepts, as well as in monitoring the quality control of the final product. Difficulties in designing an all-purpose test that simulates the major service conditions to which the majority of batteries are subjected, resulted in the initial adoption of two tests. These were devised by

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the American Society of Automotive Engineers (SAE) and were included in the Standard J537f [1]. The tests were based on constant-current discharge conditions and were designed to terminate battery life by one or other of the two principal causes of plate failure, namely, shedding of positive active material (SAE Cycling Life Test), and corrosion of the grid structure (SAE Overcharge Life Test). Thus, the principal aim of these tests was to evaluate the performance of the internal components of batteries rather than to achieve a close simulation to actual vehicle service.

The J537f Cycling Life Test subjected a battery to relatively deep cycling charges (5 A for 5 h) and discharges (20 A for 1 h). Whilst this gave a satisfactory indication of battery life in vehicles fitted with dynamos, it gave misleading results when applied to batteries in present-day vehicles. In the latter, potential is held approximately constant and the battery generally undergoes only relatively shallow cycling, the main exception being when auxiliaries are used during parking. Thus, with the advent of the alternator, a new type of life test, based on constant-potential conditions, had to be developed.

The SAE J240a Life Test, also devised by the Society of Automotive Engineers [2], simulates automotive service where the battery operates in a voltage-regulated charging system. The test procedure subjects the battery to charge and discharge cycles which result in failure modes comparable with those experienced in motor car service. SAE J240a has been widely accepted by both manufacturers and consumers, although modificiation may be required with the recent appearance of maintenance-free batteries (*v.s.*) on the market.

Problems have been encountered in the development of reliable equipment to carry out the SAE J240a test, the chief of these being transistor failure through thermal fatigue. This paper describes a design which uses the same transistors for the charge and discharge functions of the test. Such an arrangement reduces the extent of thermal cycling and has resulted in trouble-free operation of the equipment for a period greater than a year.

SAE J240a test procedure

This test only applies to 12 V (*i.e.*, 6 cell) automotive batteries of 180 min or less reserve capacity* and involves the following procedure (as paraphrased from ref. 2):

(1) The battery is tested in a water bath maintained at 40.6 ± 2.8 °C.
(2) Discharge: 2 min ± 1 s at 25 ± 0.05 A;
Charge: (i) Maximum battery voltage: 14.8 ± 0.03 V
(ii) Maximum rate: 25 ± 0.05 A
(iii) Time: 10 min ± 3 s.

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*The reserve rating is a term used in automotive battery standards to indicate the number of minutes for which a fully-charged battery is capable of supplying a given current (usually 25 A) for lighting and ignition following generator failure.

(3) The battery is continuously cycled for 100 h (*i.e.*, 500 charge/discharge operations). A switching delay of not more than 10 s is permitted from termination of charge to start of discharge and from termination of discharge to start of charge.

(4) The battery is given a 60 h stand on open-circuit in the water bath.

(5) At the temperature obtained in (4), the battery is discharged manually at a rate equal to its −17.8 °C cold cranking rate (in amperes)* to a terminal voltage of 7.2 V (*i.e.*, an average of 1.2 V per cell), or a minimum discharge time of 30 s, whichever occurs first.

(6) The battery is replaced on the life test without a separate recharge. The test is recommenced on the "charge" portion of the cycle.

(7) The life test is considered to be completed when the battery terminal voltage falls below 7.2 V at 30 s on the manual discharge. The point of failure is determined by plotting the 30 s discharge values of the battery terminal voltage.

(8) Water is added as required during the cycling portion of the test.

The SAE J240a test is a constant-potential test designed to simulate in-vehicle service conditions. The discharge on SAE J240a removes 50 amp-min from the battery (*cf.*, 1200 amp-min under old Cycling Life Test, *v.s.*) and this relatively shallow cycling is considered to be representative of the intermittent battery output required for driving under city or slow traffic conditions. A stand of 60 h on open-circuit is included to simulate the periods when the vehicle is not in use. The maximum regulated voltage (*i.e.*, 14.8 V for 6-cell battery) is set above the level normally experienced in vehicles (*i.e.*, 13.8 - 14.2 V for 6-cell battery) in order to accelerate the life test. Investigations have shown that this practice does not change the failure mode of the battery. However, accelerating the test by using higher (or lower) water-bath temperatures is likely to result in failure modes that are not obtained in service. A maximum charging rate of 25 A is used as this is typical of alternator output, less the accessory load, with the engine running at a cruising speed under favourable driving conditions.

Design of SAE J240a test equipment

The CSIRO test equipment is based on a master/slave concept in order to reduce both construction time and cost. The master test station is equipped with a timing device that regulates the circuitry of each slave unit. Under control from the master station, each slave unit tests one battery. In the event of a mains power failure, the test equipment automatically ceases operation and then has to be reset for further service. A photograph of a test rig employing a master and five slave units is given in Fig. 1.

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*Cranking performance is a term used in automotive battery standards to indicate the current which a battery can continuously deliver at a given temperature (*e.g.*, −17.8 °C) to crank the engine before falling to a specified cut-off voltage (*e.g.*, 7.2 V for a 6-cell system).

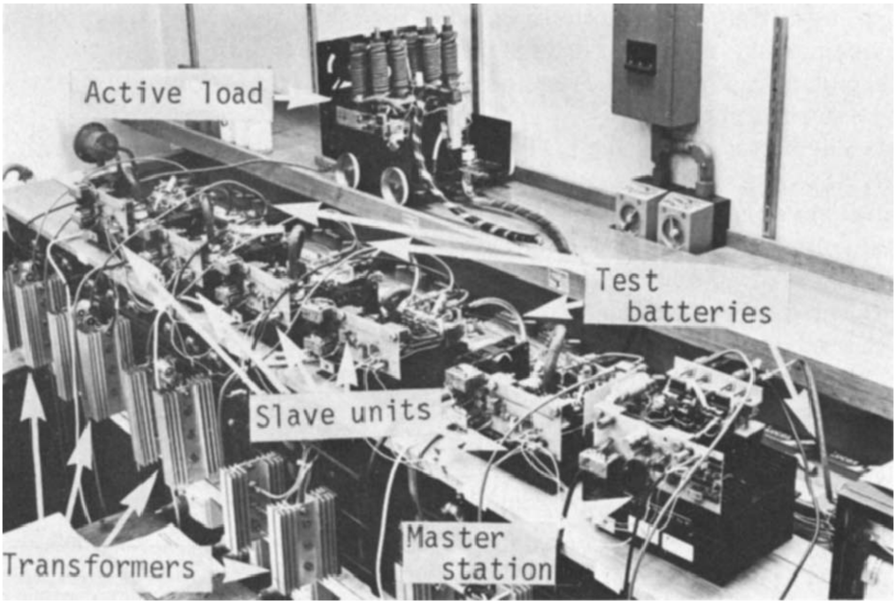

Fig. 1. SAE J240a test rig consisting of 1 master station and 5 slave units. The 3-phase transformers below the battery stations provide the charging power. An active load on the ledge above is used for discharging the batteries at the cold-cranking rate after a 60 h stand on open-circuit.

Active load charger unit

Figure 2 shows the circuit diagram of the active load/charger unit. The device operates as follows. When relays B, C and D are not energized, the circuit is an accurate current source, *i.e.*, a battery charger. A 0.025 V reference voltage is generated by the LH0070-2 intergrated circuit and 390 kΩ/1 kΩ potential divider. The feedback around the AD517L operational amplifier forces the 0.025 V reference signal across the 0.05 V/50 A shunt and thereby produces a constant current of 25 A from the 18 V floating supply. This current is used to charge the test battery. When the potential of the battery reaches 14.77 V, the LF351 amplifier output changes from —16 V to about +1 V. This positive voltage on the gate of the 2N6660 transistor lowers the channel resistance, and, hence, the reference voltage, so that the battery charging current decreases. Energizing relays B, C and D converts the station to a constant-current sink; the 0.025 V reference signal at the input of the AD517L operational amplifier ensures that a steady 25 A discharge is taken from the battery.

Component layout of the active load/charger circuit is important. The resistance of both the leads and relay contacts must be kept to a minimum in order to prevent the battery potential exceeding the SAE J240a specified limit, *viz.*, 14.8 V. The same power transistors (IRF131 and WT4313) are used to control both the charge and discharge currents. With this arrange-

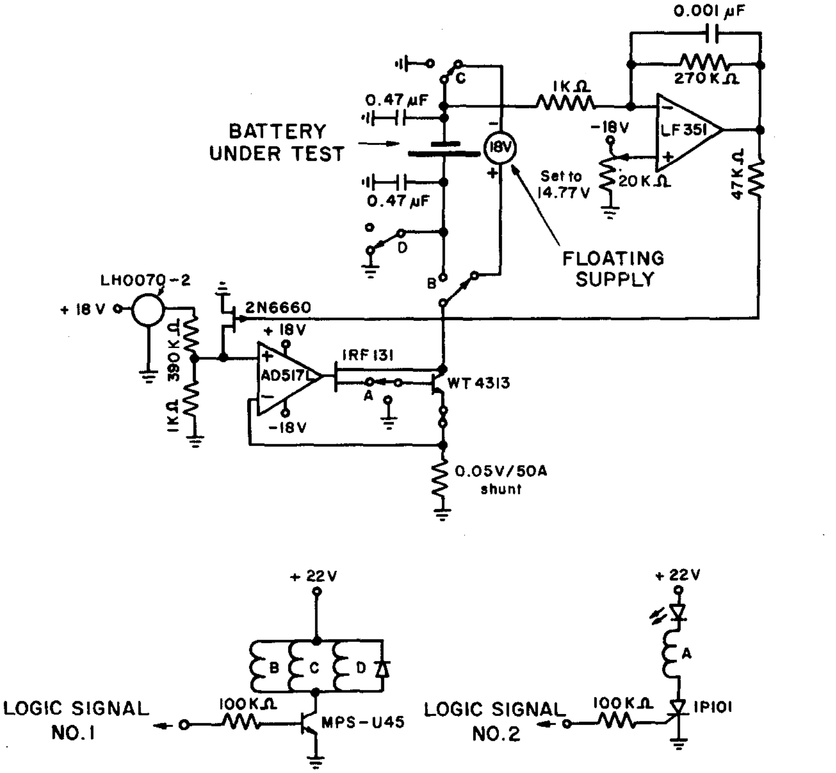

Fig. 2. Circuit diagram of active load/charger unit for SAE J240a test stations.

ment, the transistors are not subject to fatigue by thermal cycling [3]; unacceptably short transistor lives were experienced in early circuit designs that had separate transistor banks for the charge and discharge functions. The active load wiring is similar to that used in radio-frequency amplifier circuitry in order to avoid oscillation at high-rate discharge [4]. Finally, it has been found essential to power the relays from a separate supply, otherwise voltages arising from ground loop currents generated from the relay coils will alter the 0.025 V reference voltage.

Timing circuit

The test stations are controlled by two logic signals (Fig. 2) and only one (the master station) requires timing circuitry since the other stations (the slave units) can be synchronised to these signals. The logic signals are buffered by an LM324 operational amplifier (Fig. 3, *v.i.*) to provide ~ 0.015 A of drive for control of the slave units. Since only ~ 0.001 A is required for each slave unit, a single master station can operate and control many such units in a test rig.

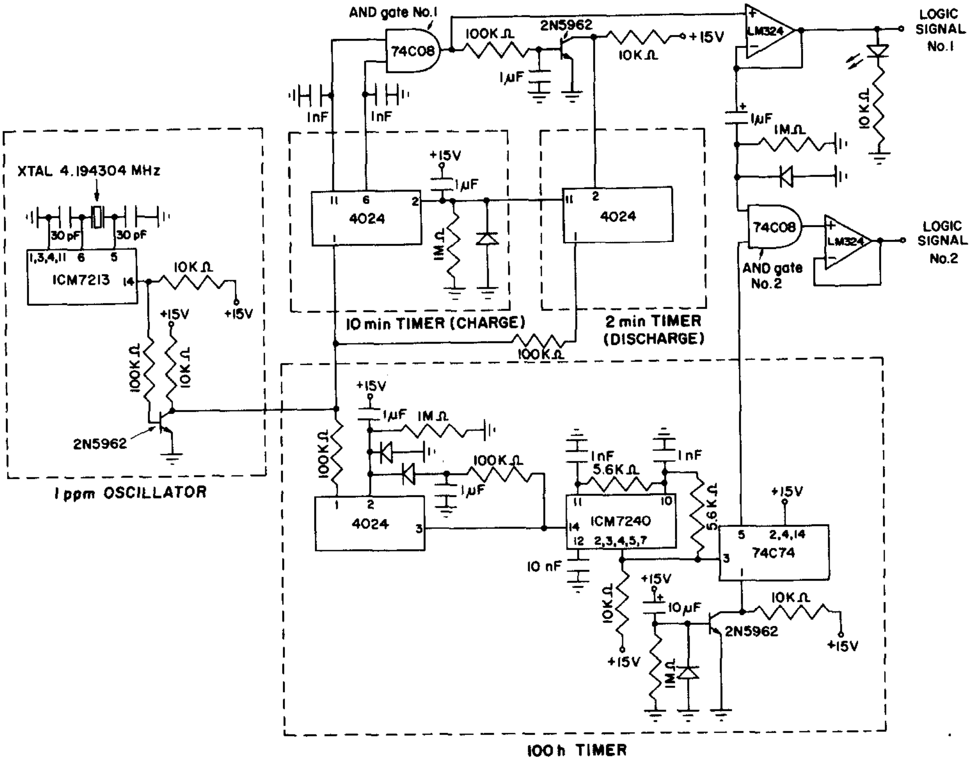

Fig. 3. Circuit diagram of timing device for master station of SAE J240a test equipment.

Figure 3 shows the timing circuit of the master station. On application of power, pulses from a crystal-controlled oscillator (integrated circuit ICM-7213) are used to drive two counters (type 4024). The pulse frequency is 1 ppm and when an interval of 10 min has elapsed (*i.e.*, the battery charge period), pins 6 and 11 on the first counter change state. This activates the 74C08 AND gate which in turn enables the second 4024 counter to monitor the 2 min period required for battery discharge. After this period, pin 11 of the counter swings to 15 V and resets the battery charge counter to zero. The charge/discharge cycle then recommences.

Under the conditions of the SAE J240a test, the charge/discharge cycling is terminated at the end of 100 h. This is achieved by energizing relay A (Fig. 2) through a sequential change in state of the No. 1 and No. 2 74C08 AND gates (Fig. 3). The 100 h period of battery cycling is controlled in the CSIRO circuit (Fig. 3) by dividing the 1 ppm frequency derived from the crystal-controlled oscillator, first by 64 (*via* the type 4024 counter), and then by 94 (*via* the programmable type 1CM7240 counter), to produce a pulse every 100.3 h. This timer accuracy is considered to be within the specifications of the SAE J240a test.

Active load for discharge at cold-cranking rate

A specially designed active load was constructed for the discharge at the cold-cranking rate. The circuit diagram for a 275 A unit is shown in Fig. 4. The device consists of four WT4313 power transistors (in parallel arrangement) with each emitter connected in series to a 0.05 Ω resistor to ensure even distribution of the emitter currents. The active load is of the open-loop type since equipment of this design is not subject to oscillation at high current. The problem of d.c. drift with open-loop loads was considered unimportant under the conditions of the SAE J240a test where discharge is required for only a short period, *viz.*, 30 s.

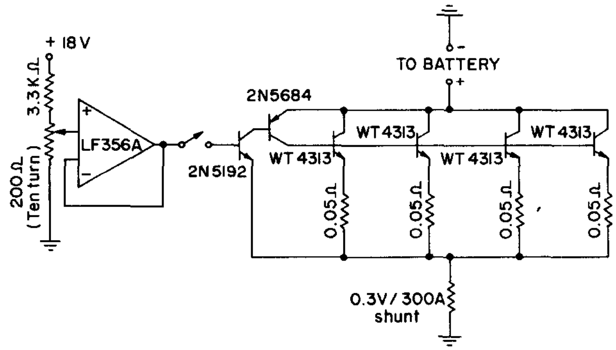

Fig. 4. Circuit diagram of 275-A open-loop active load for SAE J240a test equipment.

Performance of SAE J240a test equipment

The equipment described above has been used in a project aimed at evaluating the performance of battery additives [5]. In these studies, life tests have been carried out on 12 V batteries using a rig consisting of a master station and five slave units (as shown in Fig. 1). This rig has so far given continuous and reliable service for four years. Operating performance is better than that laid down by the specifications of the SAE J240a test procedure. For example, the current is controlled to within ± 0.005 A of 25 A and the constant-voltage feedback circuitry keeps the battery voltage to within ± 0.01 V of 14.8 V.

Typical battery performance under SAE J240a test conditions is shown in Fig. 5. In this particular case, the battery provided ~ 6000 cycles of service before the point of failure (*i.e.*, a terminal voltage of 7.2 V) was reached.

Future development

The SAE J240a Life Test was designed principally for high antimony (~ 6 wt.%) batteries. However, as mentioned in the Introduction to this paper, the current market trend in automotive batteries is towards the use of

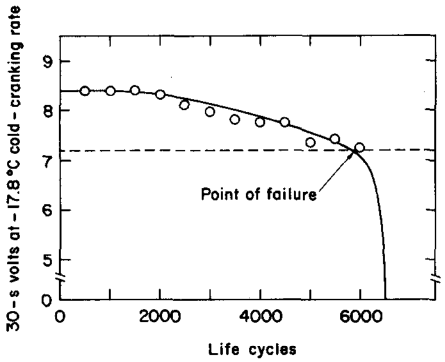

Fig. 5. Typical performance of 12 V automotive battery under SAE J240a test conditions.

maintenance-free designs. The key to the development of maintenance-free batteries has been the replacement of antimony (the strengthening agent for lead-alloy grids) by calcium. These modern lead–calcium batteries have higher Counter ElectroMotive Force (CEMF) values and, as full charge is approached, accept considerably less current than high antimonial types. This resistance to overcharge results in reduced water loss and less corrosive attack at normal charging voltages. Furthermore, whereas lead–calcium batteries have voltage characteristics which remain virtually unchanged throughout service life, this is not the case with traditional antimony systems. As these batteries age, antimony migrates to the negative plates, the CEMF is lowered, and the battery accepts more current. For example, tests carried out [6] on batteries taken from vehicles after 18 months of service revealed that although the overcharge current of lead–calcium batteries had increased only slightly (from 0.030 to 0.052 A) that for antimonial types had increased by an order of magnitude (from 0.1 to 1.1 A).

Maintenance-free batteries require excessive lengths of time to complete the SAE J240a Life Test. Thus, the test must be speeded up for these batteries. Shift in the temperature of operation (to either lower or higher values) results in battery failure modes that do not occur in actual in-car service [7], but increase in the discharge time accelerates the test without changing the causes of failure. A 4 minute discharge time has been recommended [7] for maintenance-free batteries. Further, a recent evaluation programme indicated [7] that a 6 minute discharge time may be more appropriate for antimonial batteries with reserve capacities greater than 180 min.

The CSIRO test equipment can be easily modified to accomodate these proposed changes to the SAE J240a Standard. Discharge times of 2 or 4 min can be made available by switching between different outputs on the 4024 counter (Fig. 3). Replacement of this counter by a 1CM7260 unit (with only minor circuit rearrangement) will also allow the 6 min discharge period proposed for large batteries. This flexibility of design is important in ensuring that the test equipment will not become obsolete and will accommodate any changes in test procedure which arise from future modifications in the battery requirements of the automotive vehicle electrical system.

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