Battery electrical needs for the next generation of cars

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Abstract

Electric engineering has been applied to the automobile since the 19th century when the automobile was invented. It was first for the ignition system, then a variety of electrical facilities such as for the starter, headlights, wipers, etc., were developed. At present, the battery has become indispensable for the automobile. The invention of the transistor, in 1948, brought about rapid progress of microelectronics technology, involving IC, LSI, and the microcomputer. Such technologies are now widely adopted for various functions of the automobile. This paper discusses (i) the role of electronics in the automobile, especially current and future automotive electronic systems; (ii) the electric power-supply and starter; (iii) the electrical needs of the battery.

History of electric engineering and automobiles

Electric engineering progressed rapidly in the first half of the 19th century. In 1800, Volta invented batteries. Then, Ampere formulated the law between current and potential, Ohm discovered the relation between voltage, current and resistance, and Faraday demonstrated the connection between electricity, magnetism and force. In 1866, Siemens invented the rotary generator and motor. Thus, the basics of electric engineering were established.

The first automobile prototype appeared in the latter half of the 19th century. In 1860, Otto invented a gas ignition 4-cycle engine while Lenoir introduced an electric ignition 2-cycle engine. In 1886, Dimlar installed an electric ignition 4-cycle engine on a chassis and thus became the 'father' of automobiles.

In 1911, General Motors developed a starter that enabled drivers to start an engine with a switch. Since then, all automobiles have been equipped with a battery, generator and starter. By 1940, automobiles had been equipped with an automatic transmission, power steering, speedometer, horn, air conditioner, headlights, electric wipers, etc.

The fundamental requirements of present automobiles have thus been established.

Automotive electronic systems

The transistor, invented at the Bell Telephone Laboratories in 1948, paved the way for using electronic systems in automobiles. Later, the IC was

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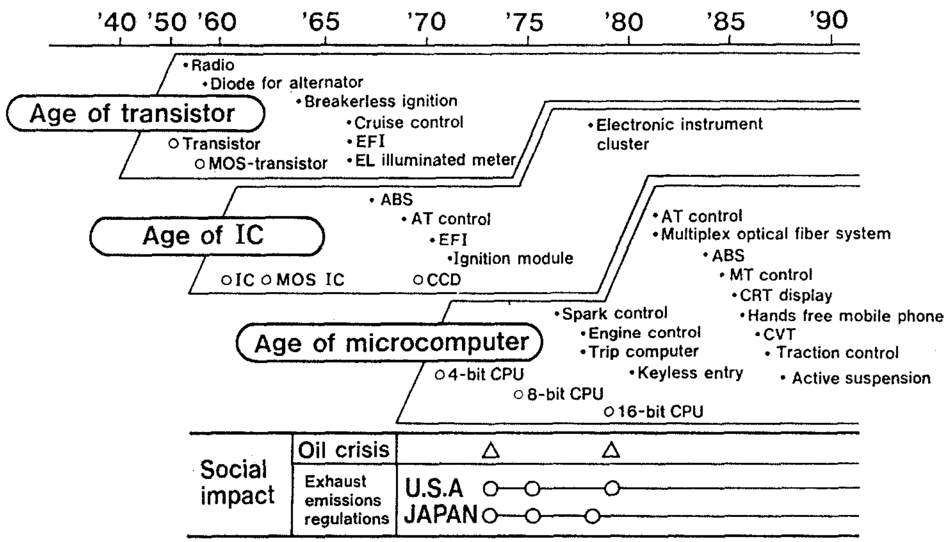


Fig. 1. Evolution in automotive electronics.

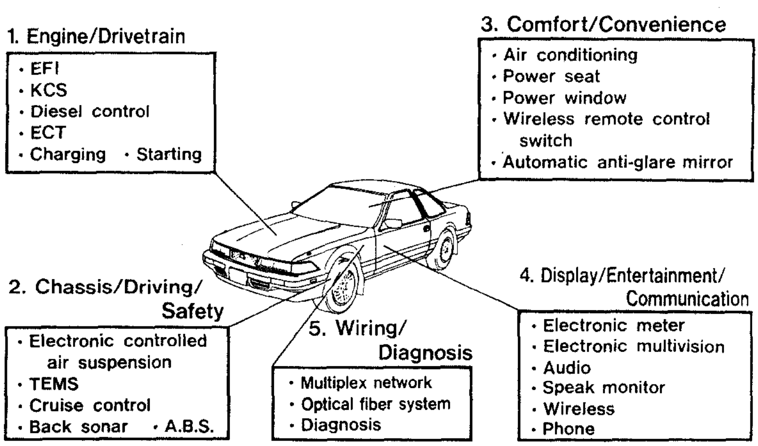


Fig. 2. Automotive electronic systems.

developed and, finally, the microcomputer was applied in automobiles. Indeed, the evolution of automotive electronics is mainly classified into the age of the transistor, the age of the IC, and the age of the microcomputer (Fig. 1).

Electronic systems recently installed in automobiles are broadly grouped into the following systems (Fig. 2):

- engine, drive train control
- chassis, driving, and safety
- comfort and convenience
- display, entertainment and communication
- wiring and diagnosis

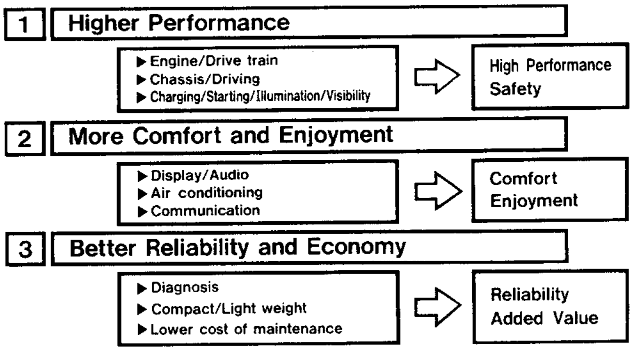


Fig. 3. Objectives of automotive electronics.

The objectives of these systems are: higher performance; more comfort and enjoyment; higher reliability and economy (Fig. 3).

Performance improvement by electronics

Basic automobile performance is increased by mechanical development while higher performance is achieved by adding electronic control technology (Fig. 4). The combination of vehicle mechanism and electronics allows the attainment of optimum tuning, automatic control, and flexibility. Development in this area in Toyota are as follows.

Optimum tuning

An example of optimum tuning is the engine, drive train control system shown in Fig. 5(a). This satisfies the requirement of high power, economy and low exhaust emission.

In the Toyota computer controlled system (TCCS), various sensor signals are gathered in an electronic control unit (ECU) that performs optimum tuning with the microcomputer under various conditions (Fig. 6). A TCCS

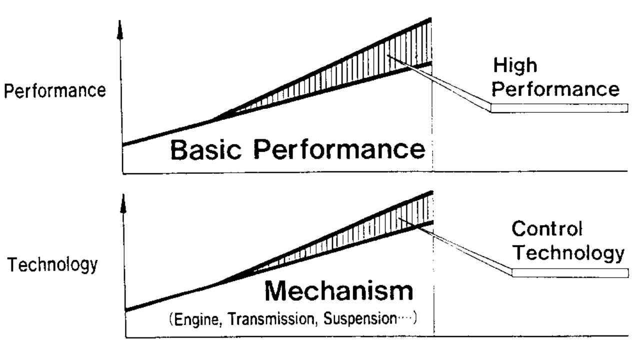


Fig. 4. Improving performance of automobiles.

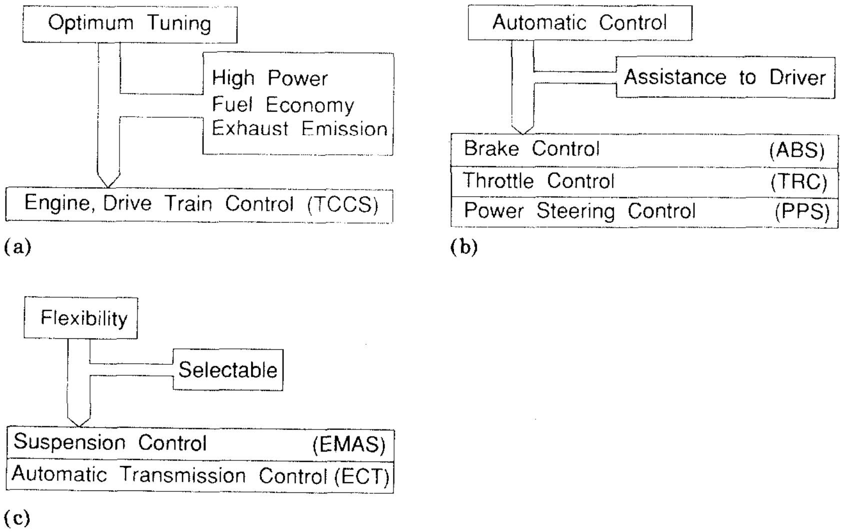


Fig. 5. Effects of electronics.

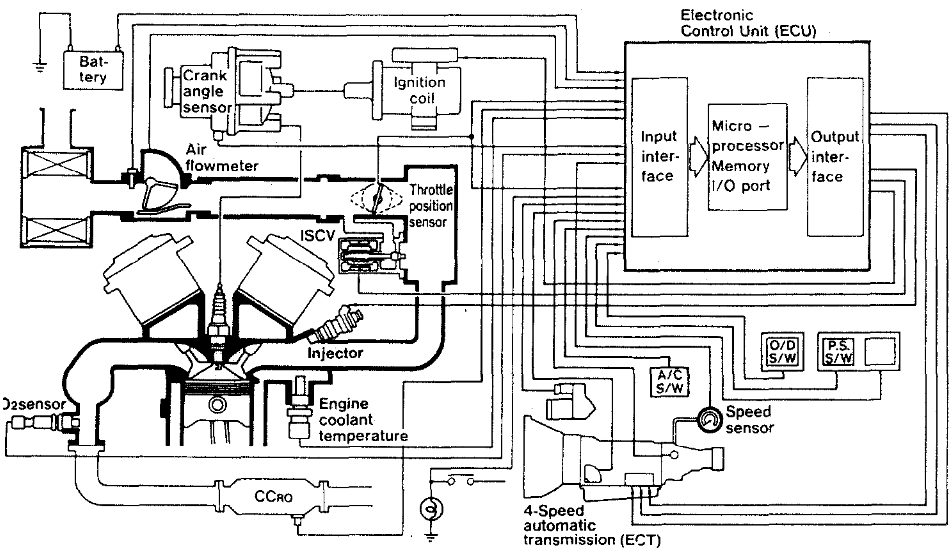
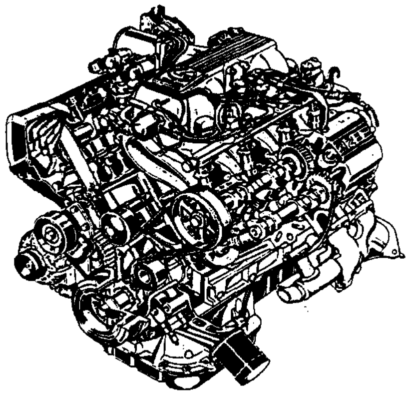


Fig. 6. Toyota computer controlled system (TCCS).

engine and its characteristics are given in Fig. 7. The engine delivers 260 HP and has a displacement of 4000 cm^3.

Automatic control

Automatic control mainly assists the driver. The ABS (anti-lock brake system), the TRC (traction control system), and the PPS (progressive power



1UZ-FE Engine

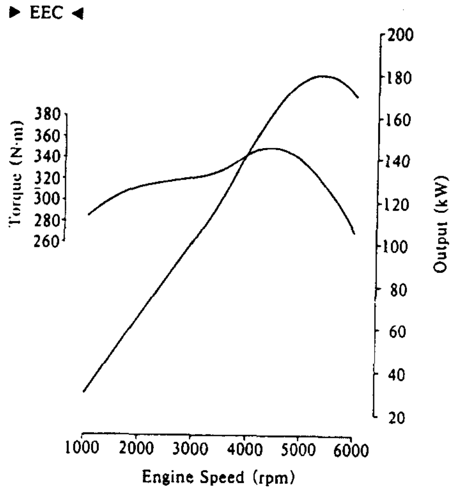


Fig. 7. TCCS engine.

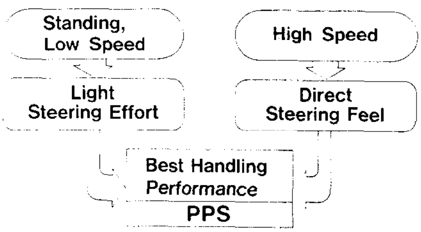


Fig. 8. Power steering control.

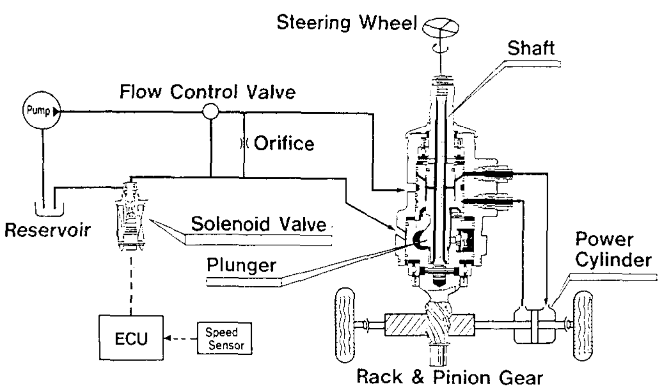


Fig. 9. Progressive power steering system (PPS).

steering) are representative of brake control, throttle control, and power steering control, respectively (Fig. 5(b)).

An example of power steering control is given in Fig. 8. Power steering is required to have a light steering effort in standing and at low speed, and to have direct steering feel at high speed. The PPS realizes these requirements and provides best handling performance. The system construction is shown in Fig. 9. The ECU controls the hydraulic pressure of the power steering by actuating a solenoid valve according to speed sensor signals. The effect of the PPS is illustrated in Fig. 10. Conventional PS becomes lighter with increasing speed, but the PPS achieves optimum sensitivity even at high speeds.

Flexibility

Flexibility provides systems with selectability (Fig. 5(c)). For instance, the EMAS (electronic modulated air suspension system) and the ECT (electronic controlled transmission system) are representative of suspension control and transmission control.

The EMAS gives a soft ride in rough roads with air suspension, small attitude change in acceleration/deceleration, and good manoeuverability at corners with electronic control. Thus, the EMAS can provide best comfort and best manoeuvrability (Fig. 11). The EMAS configuration consists of the ECU, and various sensors and actuators (Fig. 12). A schematic diagram of the EMAS is presented in Fig. 13. The auto mode select switch provides a

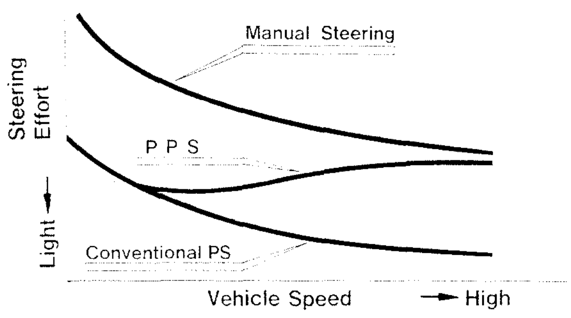


Fig. 10. Comparison of steering effort.

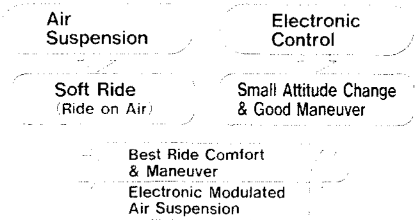


Fig. 11. Electronic modulated air suspension system (EMAS).

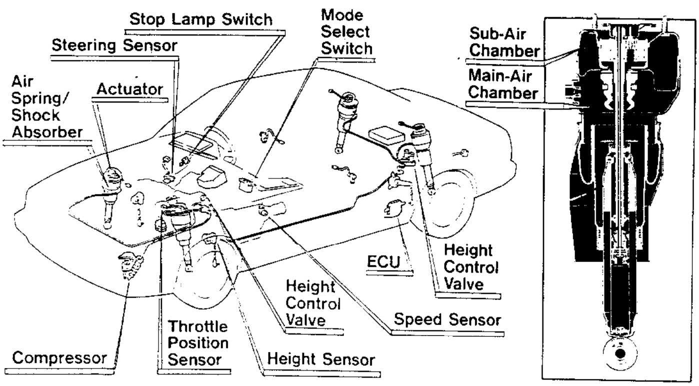


Fig. 12. Configuration of EMAS.

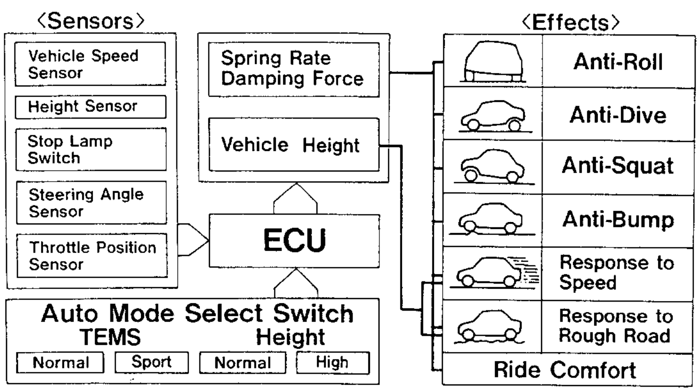


Fig. 13. Schematic diagram of the EMAS.

'normal' and 'sport' damping effect of the suspension, and a 'normal' and 'high' car height, according to user's selection. It gives flexibility in suspension properties.

Future systems

Various systems are being studied and developed for future automobiles. Some examples are as follows.

Integrated vehicle management system

Until now, various electronic systems have operated individually, but will be integrated in the future (Fig. 14). All systems such as the TCCS, ABS, TRC, PPS and EMAS mentioned above, and the others, are integrated systematically in order to achieve improved vehicle performance.

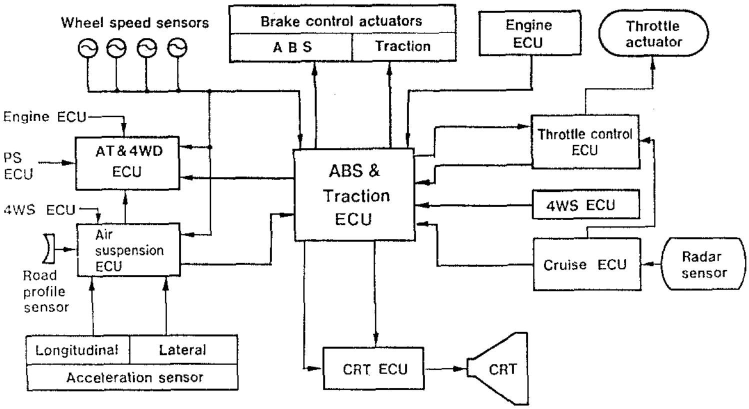


Fig. 14. Integrated vehicle management system.

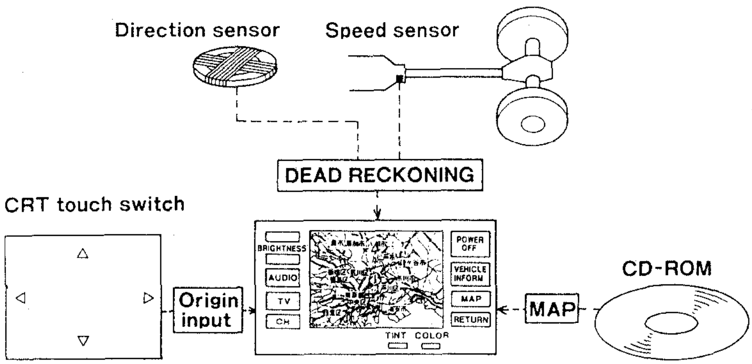


Fig. 15. Navigation system.

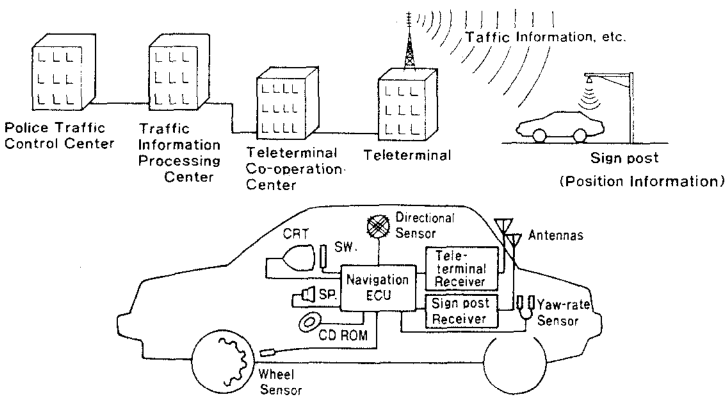


Fig. 16. Information and communication system.

Navigation system

The navigation system is shown in Fig. 15. The direction and travel distances are calculated by a direction sensor and speed sensor, respectively. The location of the automobile and the travel direction are displayed on a map stored in the CD-ROM.

Information and communication system

An example of an information and communication system is given in Fig. 16. Information sent from each tele-terminal is received by the vehicle's system of antennae and displayed on the navigation system. This latter requires an infrastructure of public systems, as well as an increase in automobile sophistication.

Electric power-supply and starters

Installation of various types of electronic systems is increasing causing a progressive increase in the electric load, particularly since about 1980 (Fig. 17). The power-supply system consists of an alternator, driven by a belt, an integrated voltage regulator, and a battery.

High-speed alternators have been developed (Fig. 18). Two small-size, inside fans are fitted at the front and rear of the rotor to improve cooling efficiency. The principle of the output increase of the alternator is shown in Fig. 19. A large current is obtained by modification of the stator coil, while the revolution speed is increased by a large drive ratio. This improves the start-up property. Output is increased by 50% compared with a conventional alternator of the same size.

With new types of engine, the cranking torque has increased because of the increased number of valves. A comparison of the cranking torque for two- and four-valved engines is given in Fig. 20. The latter requires 20% more

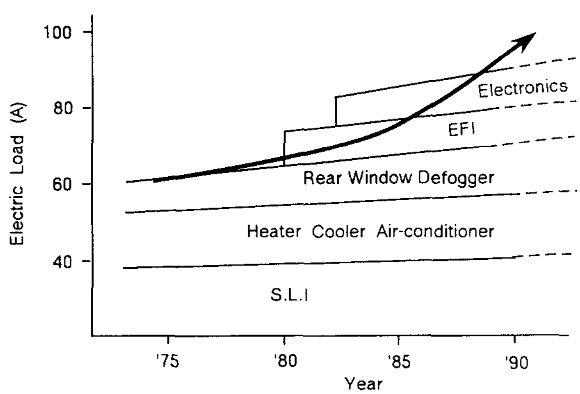


Fig. 17. Increase in electric load.

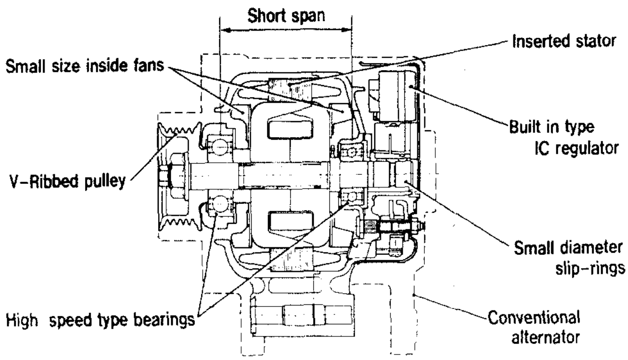


Fig. 18. High-speed alternator.

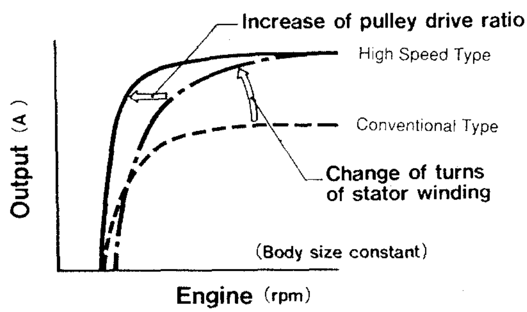


Fig. 19. Characteristics of alternator.

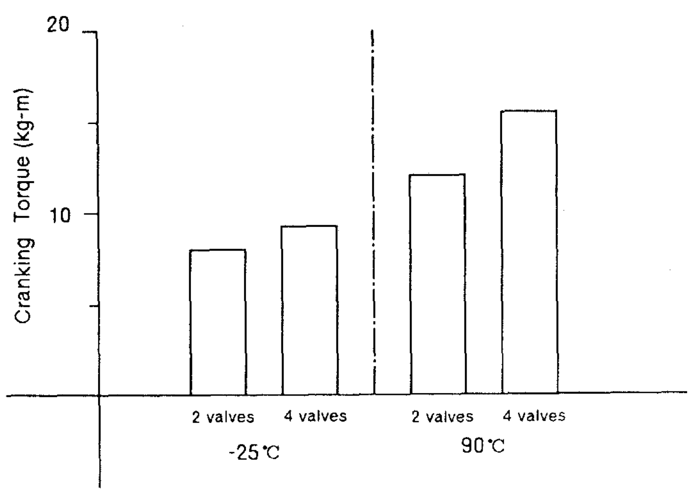


Fig. 20. Comparison of cranking torque.

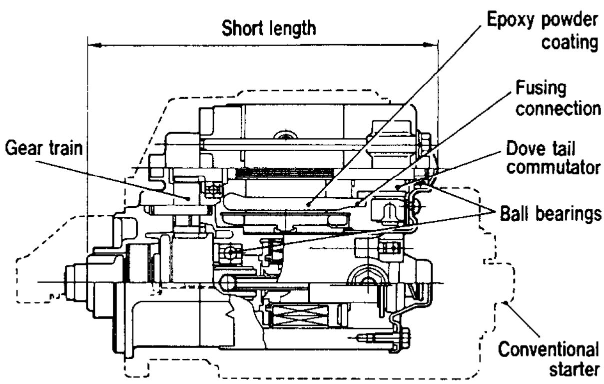


Fig. 21. Reduction-type starter.

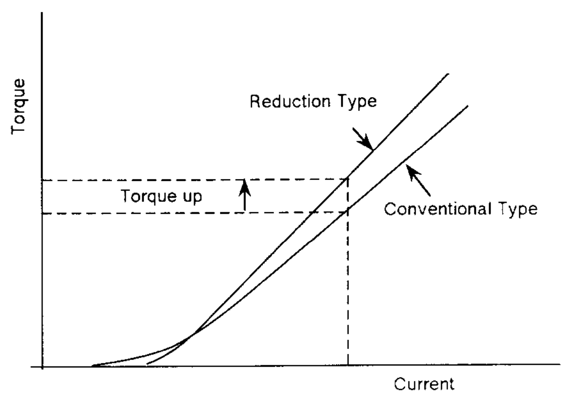


Fig. 22. Torque of starter.

torque. Furthermore, some engines require more torque at higher temperature. The design of the new reduction-type starter is presented in Fig. 21. Rotation is reduced with the gear train to improve torque. A comparison of the characteristics of reduction-type and conventional starters is shown in Fig. 22. The reduction-type supplies 20% more torque at the same current.

Electrical needs for the battery

Reduced size

As shown in Fig. 23, batteries have been reduced in size through making improvements in the components. Nevertheless, present-day batteries have larger capacity due to the increase in load current and the employment of larger engines. The current Toyota middle-size passenger cars use 80 A h units; these have twice the capacity of units employed 10 years ago.

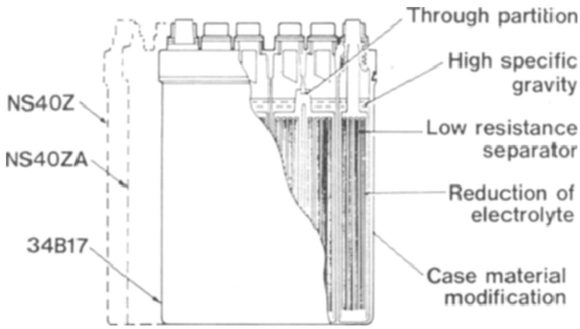


Fig. 23. Improvements in automotive batteries.

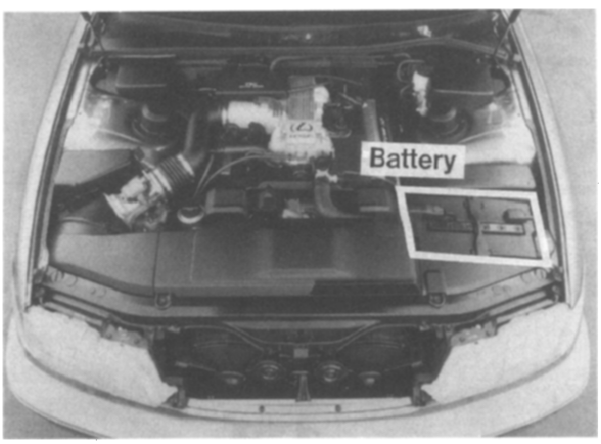


Fig. 24. Engine compartment.

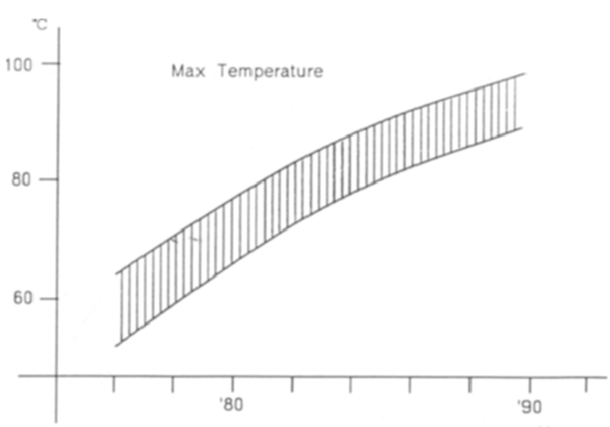


Fig. 25. Temperature in engine compartment.

In the engine compartment (Fig. 24), the battery occupies a large space compared with other parts. Thus, the battery should be sized down. At the same time, the high-rate discharge characteristics should be improved.

Better characteristics at high temperature

The engine compartment is filled with many components; these inhibit a smooth flow of cooling air. Recently, engine hoods have been lowered in order to reduce air resistance. Air intakes have therefore become smaller and this, in turn, causes a rise in temperature in the engine compartment. For example, 80 to 100 °C is experienced in the engine compartment of a middle-size passenger car during travelling, Fig. 25.

As a counter-measure, a heat insulation cover or a special chamber is provided for the battery. Nevertheless, battery characteristics at high temperature should be improved. In particular, reduction in lifetime due to over-charge in a high-temperature environment must be prevented.

Longer lifetime

The current balance of the power-supply system is shown in Fig. 26. At 40 km h^{-1}, the electrical load current is equal to the alternator output current; at lower speeds the battery is discharged, at higher speeds it is charged. The electrical load current varies according to the time (i.e., day or night) and to turning on/off the air conditioner. An example of battery charge/discharge current fluctuation during travelling along an urban street at night is presented in Fig. 27. It can be seen that the battery is appreciably discharged when the vehicle stops at intersections, but is charged rapidly when the vehicle is in motion.

In general, the SAE procedure (Fig. 28) is used for the life testing of batteries. In addition, Toyota also applies the JIS schedule (Fig. 29). The latter simulates a heavy discharge situation. The performance of conventional (lead–antimony), hybrid and calcium batteries under SAE test condi-

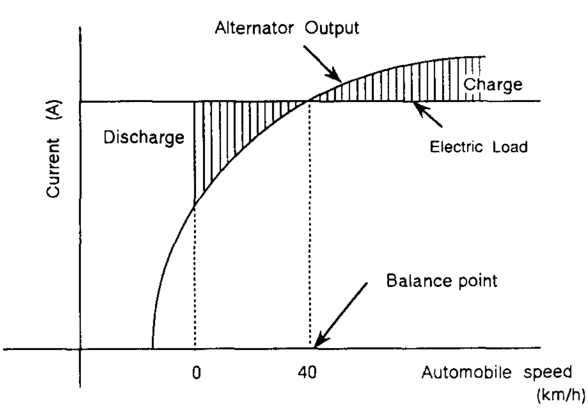


Fig. 26. Balance of electric load.

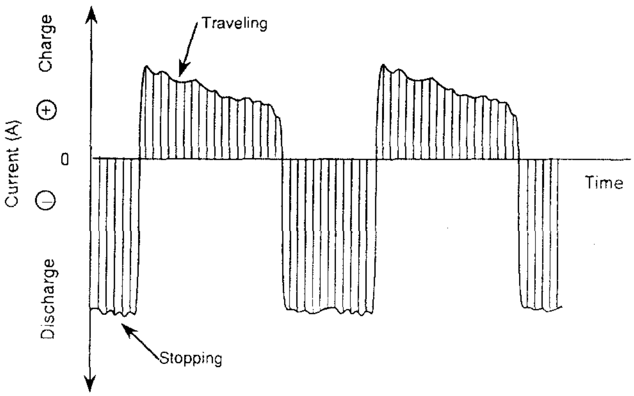


Fig. 27. Battery charge and discharge with vehicle driving.

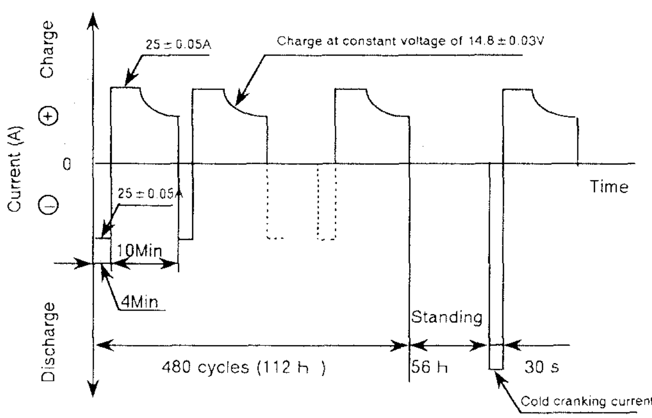


Fig. 28. SAE test schedule.

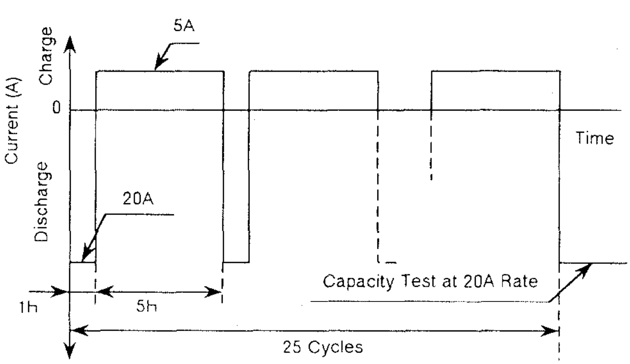
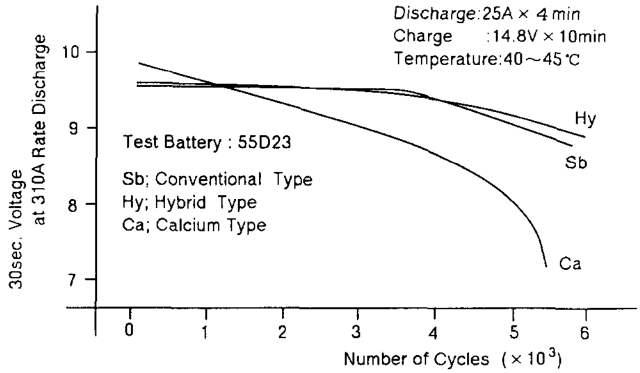
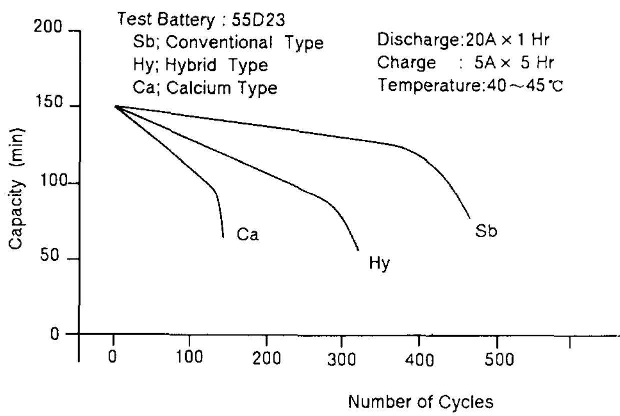


Fig. 29. JIS test schedule.



(a)



(b)

Fig. 30. Battery life under (a) SAE and (b) JIS test conditions.

tions is shown in Fig. 30(a). It can be seen that calcium batteries are inferior to the others. The same also holds under the JIS procedure (Fig. 30(b)).

Lower maintenance

It has become common practice for a vehicle owner not to open the vehicle's load, and to forget battery water addition. Thus, batteries must require less water maintenance. In this respect, calcium batteries are superior (Fig. 31). Toyota uses both hybrid and calcium types for private cars and conventional types for taxis.

Improved shelf-life

Since automobiles are exported all over the world, they are sometimes stored for long periods in ships and yards. During this time, the batteries are continuously discharged at the micro-current level because of the functioning of the digital clock and memory circuits of the electronic systems. This,

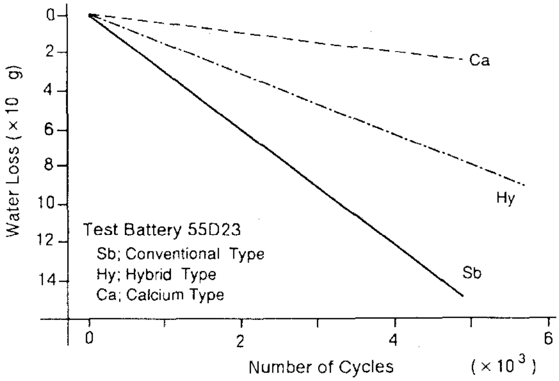


Fig. 31. Water loss (SAE test conditions).

together with normal self-discharge, results in batteries becoming completely discharged. When left for a long time after complete discharge, some calcium batteries cannot be recharged, or suffer a 50% reduction in capacity. This behaviour must be overcome.

Better reliability

Internal defective connections and short-circuits may cause failure of the battery. Reliability must be achieved in both design and manufacture. The failure rate should be less than 1 in 100 000.

Leakage of electrolyte sometimes occurs due to over-charge or damage to the battery container. There are many connections to the electronic systems in the engine compartment. Although these connections are waterproofed, contact with battery electrolyte should be avoided.

There are two causes of battery explosion: external flashing to inside gas, and internal short-circuit. To prevent external flashing, a ceramic filter is used for the vent hole. The filter must be kept dry, otherwise its permeability is decreased and hydrogen gas accumulates inside the batteries thus causing explosion.

External connection terminals should be also reliable. For the electronic systems, power supply must be continuous. It is important that the connection terminals be improved.

Conclusions

The effects and trends of automotive electronic systems, the development of the charging system and starter, and the electrical needs of the battery have been discussed. Automobiles in the next generation will be equipped with many more electronic systems in order to achieve higher speed, a greater degree of comfort, and safety. The fundamental unit of electronic systems is the power-supply system. This consists of the alternator and the battery. The latter is most important and the required performance of batteries has been increasing year by year. A higher level of battery reliability is also necessary in order to achieve customer satisfaction. It is therefore essential to improve conventional items and develop new batteries.