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The MARS II Electric Car

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THE PURPOSE OF THIS PAPER is to describe a compact, four door, five passenger electric car, called "MARS II," shown in Figs. 1 and 2. This car was recently developed to provide economical, non-air-polluting private transportation to urban and suburban residents of metropolitan areas suffering from the ill effects of increasing air pollution due, in large part, to the increasing population of internal combustion engine cars in those areas. (1)*

The MARS II is a second generation vehicle developed in January, 1967; its predecessor, called MARS I, having been built in August, 1966. (2) Besides providing a non-polluting vehicle, its developers sought to create a vehicle which could be operated quietly and thereby contribute to lowering the noise level in large cities; which would be comparatively uncomplicated and easy to maintain; and which would be economical to operate.

In the process of developing these cars, considerable work was done in designing the principal propulsion components and systems, the most important of which were the battery and the regenerative braking system.

ELECTRIC PROPULSION SYSTEM

TRI-POLAR, LEAD-COBALT BATTERY - Four, 30 v, 290 amp-hr batteries are used in the MARS II. The most significant advantages of these batteries are that they can deliver approximately twice as much energy per pound as ordinary lead-acid batteries (3), and can be safely recharged

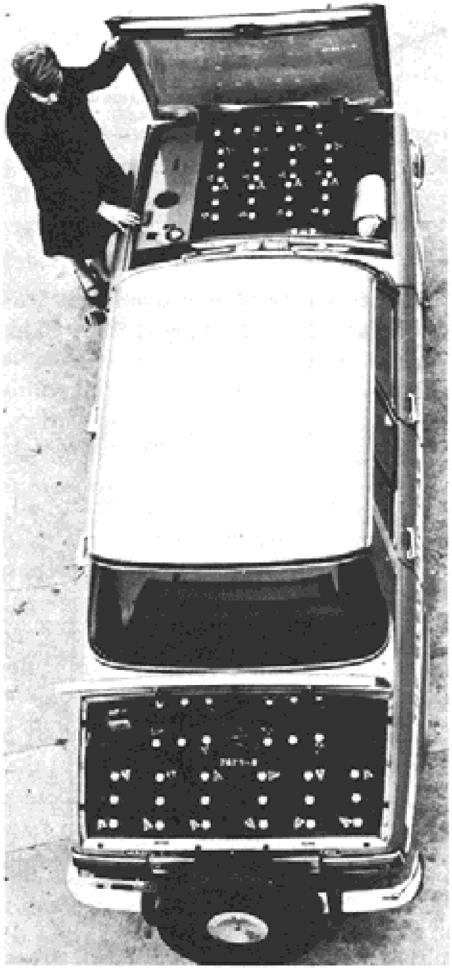

Fig. 1 - Top view of 1968 Mars II electric car

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*Numbers in parentheses designate References at end of paper.

ABSTRACT

A new electric car has been developed which has a maximum speed of 60 mph, a driving range of 70-120 miles on a charge, and which can be recharged to 80% capacity in 46 minutes. The car's tri-polar, lead-cobalt battery and regenerative braking system are described in detail. The average city or suburban resident could utilize such a vehicle for most of his driving requirements up to 70 miles a day, or under certain conditions, up to 230 miles a day.

Fig. 2 - Side view of 1968 Mars II electric car

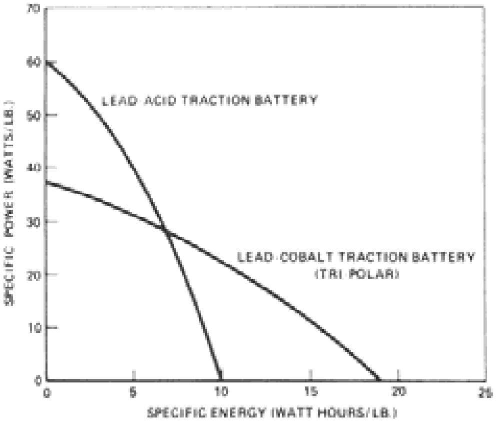
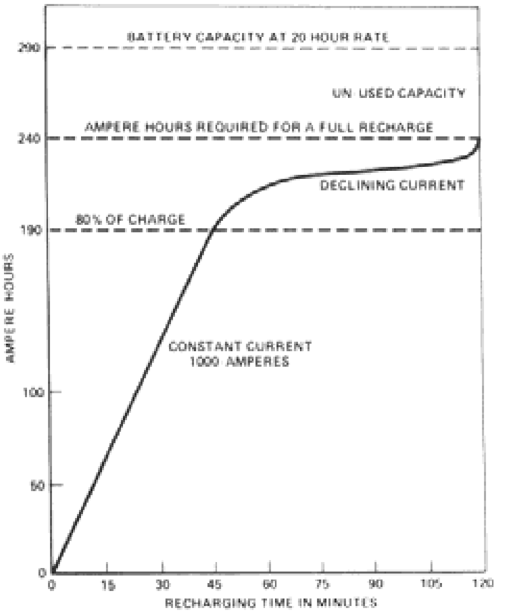


Fig. 3 - Specific energy versus specific power in lead-acid versus lead-cobalt batteries (tri-polar) at 80 F, 20 hr discharge rate to 1.5 v per cell



120-VOLT BATTERY, ARRANGED AS FOUR 30-VOLT UNITS IN PARALLEL

WHEN 240 AMPERE HOURS HAVE BEEN USED, BATTERIES ARE FULLY DISCHARGED FOR ALL PRACTICAL PURPOSES

Fig. 4 - Time required to recharge a 30 kwh tri-polar lead-cobalt battery

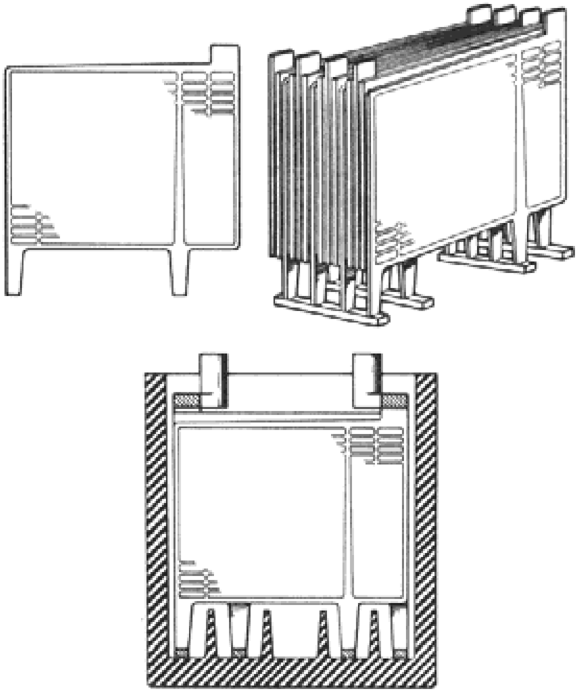


Fig. 5 - Tri-polar cell construction

at high currents to 80% of capacity in 46 minutes. (See Figs. 3 and 4.)

Figs. 5 and 6 show the tri-polar, lead-cobalt cell design wherein all the positive plates in a group of plates within a cell are connected to one another in three places structurally and electrically, forming, in effect, three poles. All the negative plates are also connected to one another in the same manner. The cell element is thus equipped with six current collecting bus bars, two at the top of the cell and four additional at the bottom. In ordinary lead-acid batteries there are only two such bus bars at the top of the cell, the plates being unconnected and loose at the bottom and subject to buckling (with subsequent fracturing of separators) and vibration (with subsequent loosening and shedding of active plate material).

Several advantages of this construction follow:

1. The multiple interplate electrical connections enhance the ability of the cell to deliver and accept high current as the number of interplate current paths which divide the current flow through the cell increases the total current which the cell can handle, while decreasing the current through each individual current path.

2. The bottom four bus bars rest on the floor of the container, supporting the entire weight of the cell element through current and heat conducting legs. These bars induce the normally cold and dormant acid which lies near the bottom of the container to rise and circulate up through the cell whenever the temperature of the plates, when charging and discharging, rises above that of the acid at the bottom of the cell. A recirculating electrolyte system is thus built into each cell.

3. Interplate structural connections at top and bottom

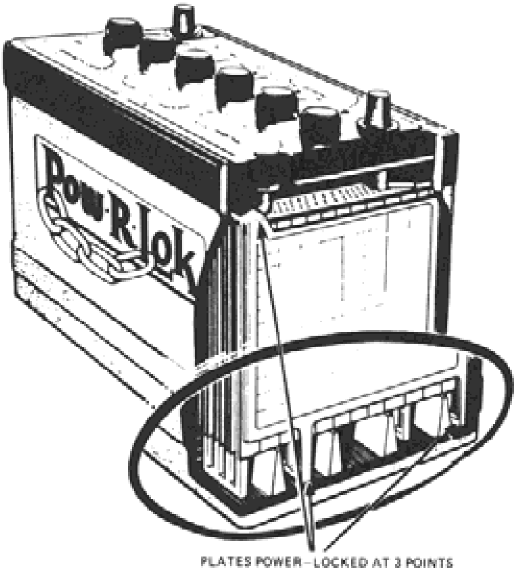


Fig. 6 - Cut-away section of tri-polar, lead-cobalt battery

of each plate prevent plate buckling and distortion, thereby allowing plate insulators or separators to perform properly without danger of fracture, abrasion, and wearing or cutting through by the corners of the plates.

4. Multiple interplate structural connections reduce plate vibration and resultant loosening and shedding of power producing active plate material.

5. Plates can be charged and discharged even though they may become broken through the center or become detached from the terminal, or from any one of the poles.

Another advantage of the tri-polar, lead-cobalt battery, stemming primarily from the use of cobalt in the cells, is that the production of harmful gases within the cells is virtually eliminated. One of the products of the charging process in ordinary lead-acid batteries is the emission of stibine, the hydride of antimony SbH_3, a very toxic gas. (4) Antimony is commonly combined with lead in the manufacture of lead-antimony grids of lead-acid batteries, the antimony being needed to strengthen and stiffen the grid so that it can be handled, pasted, and processed without distortion and bending. Other materials could be used to stiffen the soft lead, such as calcium, but they are expensive and difficult to process when alloyed with lead. In ordinary lead-acid batteries, antimony in the positive plate grids dissolves in the electrolyte and migrates to and deposits on the active material of the negative plate, setting up a local couple or closed circuit between the sponge lead of the plate and the antimony. Antimony in the grids also dissolves in chlorine which is contained in most water used in batteries (although distilled water should be used), and deposits on the negative plates. Overcharge of the battery with the resultant oxidation of positive grids accelerates the process of antimony transfer from positive grid to negative plate.

To retard this process, the sulphuric acid electrolyte of the tri-polar battery contains a solution of cobaltous sulphate which forms a protective coating on the positive grid, in effect sealing in the antimony and preventing the dissolution and migration of antimony from positive grid to negative plate. Thus, the production of stibine gas during the charging process is virtually eliminated. Another advantage of the use of cobalt is the protection of the positive grids from oxidation as a result of the normal charging process, or overcharging. Also, the use of cobalt reduces the polarization of the positive plates, lowering the required charging voltage and enabling the plates to become recharged more rapidly.

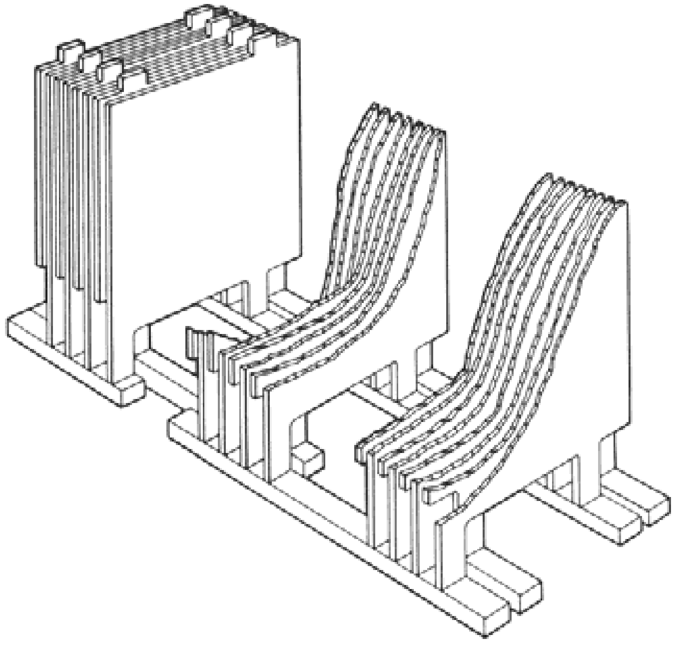


Fig. 7 - Floor section of improved tri-polar battery

An improvement in the tri-polar principle, shown in Fig. 7, not yet incorporated in production batteries used in the cars, has recently been developed wherein the three poles of a group of plates within a cell are connected in series with the three poles of the group of plates of opposite polarity in the adjacent cell. This inter-cell arrangement, by providing a number of intercellular current paths which divide the current flow through the battery, increases the total current which a given battery can handle while decreasing the current through each individual current path. Should any particular intercellular connection fail, the battery can still operate as long as the current which must be carried does not exceed the abilities of the remaining connections to withstand it. This ability to carry high electrical current makes the improved battery ideal for use in situations where a high current is needed to perform work and where a high current is available for recharging the battery.

In addition, with this improvement, it is not necessary for current generated near the bottom of every plate to travel up through a plate to reach the intercellular current path through the straps connecting the cells. Providing current paths through the cells at the bottom of the plates decreases the current flow in the upper and middle parts of each plate, and increases the ability of the plates themselves to produce and carry heavy currents.

Furthermore, by providing a number of current paths so

Table 1 - Specific Energy Of 30 kwh Tri-Polar, Lead-Cobalt Battery (1900 lb) Operated In MARS II (4260 lb gvw)

Average Cruising Speed	30	40	50	60
Range, miles	120	100	80	60
Average Discharge Voltage**	116	115	110	105
Discharge Time, hr	4.0	2.5	1.6	1.0
Discharge Current, amp	60.0	80.0	120.0	180.0
Ampere Hours Available	240	200	192	180
Watt Hours	27,840	23,000	21,120	18,900
Watt Hours Per Pound Of Battery	14.6	12.2	11.1	9.9
Miles per kwh	4.3	4.3	3.8	3.1

At 80 F To End Voltage Of 90 v

**Initial Discharge Voltage	121	120	115	105
Average Cruising Speed	30	40	50	60

that the distance travelled by current generated in the bottom portion of the plate is considerably reduced, the resistance of the average current path, and hence, the internal battery power losses are considerably reduced. This, of course, frees a portion of the stored energy, which was formerly lost within the battery, for useful external work.

Laboratory models of the improved battery indicate an increase of approximately 20% in current density over the existing battery.

Specific Energy - The specific energy, or watt-hours per pound, of the battery used in the MARS II is 17.8 at the 20 hr rate, with discharge current at 14.5 amp and average discharge voltage 117 v. Table 1 and Fig. 8 show the extent of specific energy available at different driving speeds. As can be seen, the efficiency of utilization of battery power is an inverse function of speed. Although there are many reasons for this, perhaps the most significant is the relation between the rate of formation of water in the pores of the plates (or rate of deconcentration of acid in the pores) and the rate of diffusion of the water thus formed into the acid electrolyte outside of the plates. The faster the rate of discharge, the faster the formation of water in the pores of the plates. As the concentration of acid in the pores of the plates is a vital factor determining voltage and capacity of the cell, the faster water accumulates in these pores, the quicker the effective capacity of the cell is depleted. When the speed of an electric car is low (25-30 mph) and current requirements are low, the speed of diffusion of water from the interior portion of the plates to the exterior is relatively greater than when the car is traveling at a higher speed. Thus, the lower the vehicle speed, the greater the specific energy available.

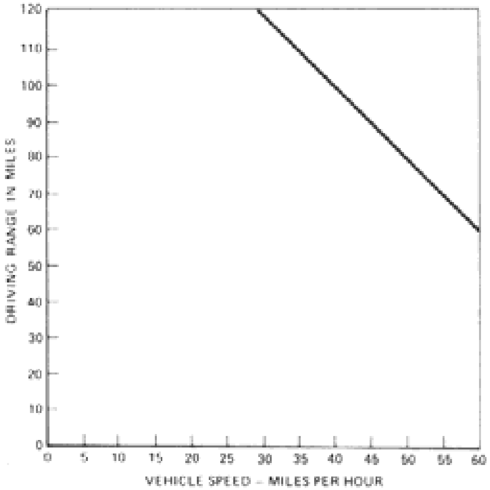


Fig. 8 - Vehicle speed versus driving range in Mars II (4260 lb gvw)

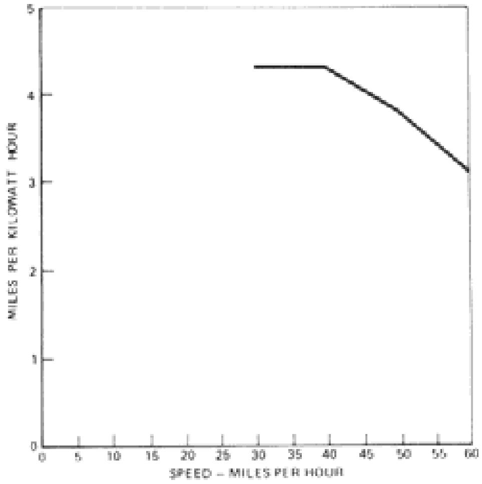


Fig. 9 - Rate of energy consumption versus vehicle speed in Mars II

Translated into miles per kilowatt hour, 3.1 miles per kilowatt hour can be obtained while traveling at 60 mph, while 4.3 miles per kilowatt hour can be obtained while traveling at 30 mph, as shown in Fig. 9.

Specific Power - Specific power, or watts per pound, of the battery used in MARS II ranges from 3.8 w/lb while the car is cruising at 30 mph to 37.8 w/lb at peak acceleration. (See Table 2.) The greater the speed of the vehicle and specific power required, the lower the availability of specific energy, as shown in Fig. 10.

CONTROLLER - Battery current is transmitted to the motor through a control panel, in which a number of magnetically operated contactors are arranged in such a way as to enable the operator of the vehicle to switch applied voltage and current at will through seven steps by applying foot pressure to the accelerator pedal.

The controller design enables the driver of the vehicle to operate the car's four 30 v batteries in parallel when starting and operating at low speeds (0-15 mph), in series-parallel 60 v -- at intermediate speeds (15-30 mph), and in series --

Table 2 - Specific Power Of 30 kwh Tri-Polar, Lead-Cobalt Battery (1900 lb) Operated In MARS II (4260 lb gvw)

Cruising Speed, mph	30	40	50	60	peak acceleration
Discharge Voltage	123	121	120	115	90
Discharge Current	60	80	120	180	800
Watts	7,380	9,680	14,400	20,700	72,000
Watts per Pound Produced	3.8	5.1	7.5	10.9	37.8

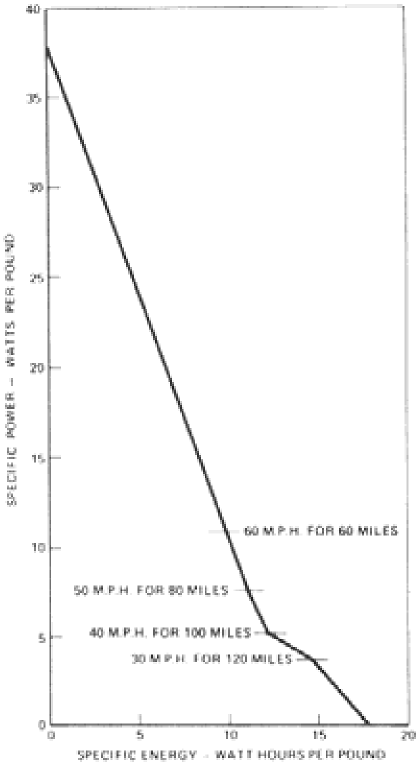


Fig. 10 - Specific power versus specific energy in 30 kwh tri-polar, lead-cobalt battery (1900 lb), gross vehicle weight of car - 4260 lb (curb weight - 4100 lb)

120 v -- at higher speeds. The advantage of this is that at low and intermediate speeds, the specific energy of the batteries can be utilized more efficiently in parallel and series-parallel operation than if they were operated in series. For example, at low speeds, with all batteries in parallel, each battery would contribute only one-quarter of the motor current required.

Another advantage of being able to operate the batteries in parallel at low speeds is that they can better handle large surges of current often required by the motor, for example, when climbing a steep ramp in a parking garage. A surge requirement of 1000 amp can be handled better by a 30 v, 1160 amp-hr battery (four 290-AH batteries in parallel) than by a 120 v, 290 amp-hr battery.

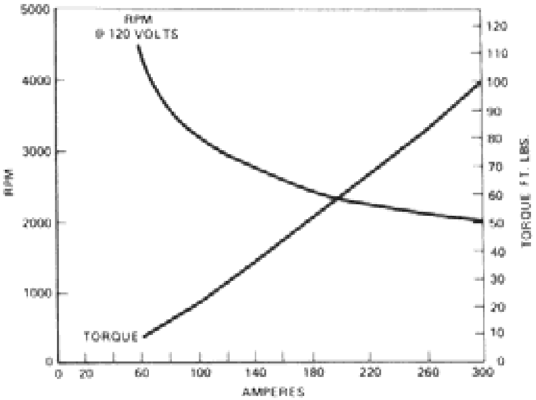


Fig. 11 - Performance characteristics of Mars II traction motor-direct current, series wound

A further advantage of operating the batteries in parallel is that the batteries can be charged in parallel, which provides for automatic equalizing of charge among the four batteries, thereby lessening the danger of overcharge of any of the batteries. In addition, charging at 30 v is safer to persons who may be in contact with the car than charging at 120 v.

MOTOR - A direct current, series wound traction motor is used in the vehicle which can develop up to 77 hp at peak acceleration. Table 3 and Fig. 11 show motor performance at 120 v. As is characteristic of most direct current motors, an inverse ratio exists between torque (or current) and motor speed. At a speed of 4500 rpm, torque is 9.5 ft-lb, while at a speed of 2080 rpm, torque is 100 ft-lb.

The motor is connected, through a clutch, to a 4-speed-forward, manual transmission which utilizes this relationship of torque and current to motor speed to advantage. Operating at low vehicle speeds in second gear (gear ratio 2.25), for example, results in high motor speeds and low current consumption, while operating in fourth gear (gear ratio 1.03) results in lower motor speeds, higher current consumption, and greater vehicle speeds. (See Table 4 and Fig. 12.)

REGENERATIVE BRAKING SYSTEM - An important consideration to be given to an electric car is its ability to stop quickly and safely. In addition to being equipped with a dual hydraulic braking system with disc brakes on all four

Table 3 - Motor Performance Data On MARS II
Traction Motor, Direct Current, Series Wound

Voltage	Current	Torque	Motor rpm	Horsepower	Efficiency
120	60	9.5	4500	8.1	83.9
120	80	15.5	3640	10.7	83.1
120	100	22.0	3280	13.7	85.2
120	120	29.0	3000	16.5	85.4
120	140	36.5	2800	19.4	86.1
120	160	44.0	2640	22.1	85.8
120	180	51.5	2480	24.5	84.6
120	200	59.0	2360	26.5	82.3
120	220	67.0	2280	29.0	81.9
120	240	75.0	2220	31.7	82.1
120	260	83.0	2160	34.1	81.5
120	280	92.0	2120	37.1	82.3
120	300	100.0	2080	39.6	82.0

Table 4 - Vehicle Speed Versus Horsepower In
MARS II - Batteries Fully Charged

Average Cruising Speed, mph	30	40	50	60	peak surge
Discharge Voltage	123	121	120	115	90
Discharge Current, amp	60	80	120	180	800
Watt Input	7,380	9,680	14,400	20,700	72,000
Efficiency	83.9	83.1	85.2	84.6	80.0
Horsepower	8.3	10.7	16.4	23.4	77.2

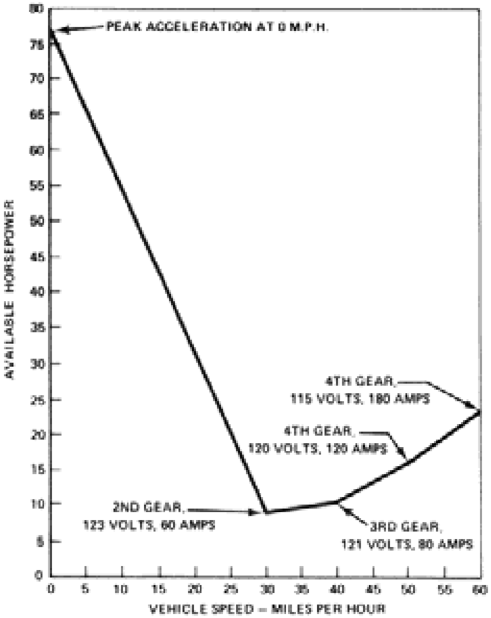


Fig. 12 - Vehicle speed versus horsepower in Mars II (4260 lb gvw)

wheels, the MARS II incorporates a novel system of supplementary braking which provides positive braking from any speed down to zero mph. The system also provides for the recovery of power consumed in the acceleration process and stored in the vehicle as kinetic energy during the braking process.

In a conventional internal combustion engine powered car, kinetic energy is uselessly dissipated as heat when the brakes are applied, whereas in the MARS II this energy can be recovered by the same action which brakes the vehicle.

In order to recover as much energy as possible, the time which elapses between the desire to brake and the actual commencement of regenerative braking must be as small as possible. The MARS II regenerative braking system satisfies this requirement by activating the regenerative apparatus whenever the accelerator control pedal is released from foot pressure. In addition to recovering the maximum kinetic energy, the arrangement also results in increased safety, since braking is initiated even before the brake pedal or any other control is touched, and braking occurs even in the event that all other braking systems fail. In second gear, at 30 mph, for example, the regenerative braking system

Table 5 - Braking Horsepower Developed By Alternator On Deceleration In Third Gear

Vehicle Speed, mph	50	40	30	20	10
Alternator, rpm	11,375	9,100	6,825	4,550	2,275
Alternator, hp	14.8	13.6	10.2	6.8	3.5
Charging, Current amp	200	160	160	133	0

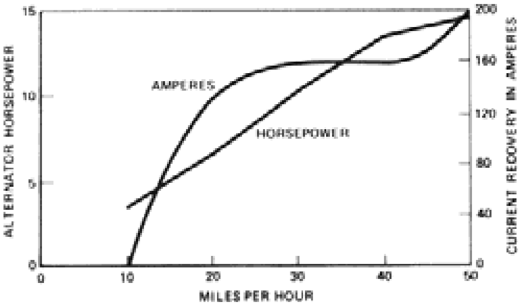


Fig. 13 - Braking horsepower and regenerative current developed by alternator on deceleration

would stop the car in approximately 500 ft. (See Fig. 13 and Table 5.)

In one specific embodiment, this recovery is accomplished through an alternator which is mechanically driven by the electric motor, which also drives the wheels, to recharge the batteries which furnish energy to drive the motor, whenever the accelerator pedal is in a position indicating that no pressure is being applied to it. This same embodiment can also be utilized for recharging the storage batteries from an exterior source, by simply exciting the electric motor from the exterior source to mechanically drive the alternator and, hence, recharge the storage batteries.

The intermittent recharging, which results whenever the accelerator pedal is in the released position, has a number of beneficial results. Whether lead-cobalt or lead-acid batteries are utilized, horizontal layering or stratification of the electrolyte in the battery, which results in a number of layers of differing ratios of acid to water with the greatest amount of acid near the bottom, is substantially prevented by the constant circulation of the electrolyte which results from intermittent recharging. As a result, more of the acid is effectively used in the discharge process, and battery life and efficiency are increased. Furthermore, this constant circulation prevents the water produced during discharge from collecting at the surface of the plates which reduces conductivity between them, thereby significantly stretching the lifetime and efficiency of the batteries.

Moreover, the extra surface charge which the batteries receive in stopping or moving down hills makes extra power immediately available for a quick start with added acceleration. This is especially important, since much more energy is required to accelerate the automobile than to move it at a constant rate. Extra power is then made available when it is most needed.

Another advantage of the regenerative braking system is that the batteries can be simply and quickly recharged form an external source of alternating current. In the embodiment discussed in detail, this is accomplished by applying an external alternating current to a rectifier circuit wholly within the automobile, and utilizing the rectified voltage thus produced to excite the electric motor. An alternator is then driven mechanically by the motor, producing an alternating current which is rectified and applied to the storage batteries. This particular arrangement produces quick and complete battery recharging whenever alternating current is available. Since the alternator produces a much higher current than the rectified external source, battery recharging time is substantially reduced.

OTHER ELECTRICAL EQUIPMENT

ALTERNATOR - A 37 v, 200 amp intermittent duty alternator is mounted parallel to the electric motor and engages the motor through a belt driven electric clutch on deceleration, developing a braking counter-torque of up to 15 hp.

ELECTRIC CLUTCH - A 75 ft-lb, magnetic type electric clutch is mounted on the motor shaft and engages on deceleration, operating pulleys and cog belts connecting motor shaft to alternator shaft.

ON-BOARD CHARGER - The car is equipped with a built-in slow charger for overnight recharging of both the four 30 v power batteries and the 12 v accessory battery. It operates on a 208/240 v, single phase, 30 amp circuit and charges the power batteries in parallel at a starting current of up to 100 amp to a final voltage of 37 1/2 v, with current declining once final voltage has been reached. It charges the accessory battery at a starting current of 15 amp to a final voltage of 14.7, with current declining once final voltage has been reached. It cannot overcharge the batteries, even if left in operation continuously for several days. Average recharging time for fully discharged batteries is 8 hr.

HIGH RATE CHARGING RECEPTACLES - These units are installed in the trunk area of the car and permit fast recharging of the power batteries at currents up to 1000 amp at 37-1/2 v from an external power source.

POWER-BATTERY VOLTMETER - This is installed on the dashboard of the car and indicates state of charge of battery while operating at 30, 60, or 120 v through color coding.

POWER-BATTERY AMMETER - This is installed on the dashboard and indicates motor current consumption on one side of meter and alternator recharging current on the other side.

ACCESSORY BATTERY VOLTMETER - This is installed on the dashboard and indicates operating voltage of the 12 v battery.

AMPEREHOUR METER - This is installed in the trunk and indicates current consumption from the power battery and current recovery during the regenerative or recharging process. A remote control electric fuel gage, operated by this meter, is installed on the dashboard to indicate amount of "electric fuel" left in the power batteries.

KILOWATT HOUR METER - This is installed in the package storage space behind the back seat. It measures and records, on a cumulative basis, input power consumption from the alternating current source to the on-board charger.

OPERATION OF VEHICLE

Operation of the car is very quiet. During acceleration from zero 0-30 mph, there is a slight whine of the direct current motor, but after that, the car operates virtually silently. On deceleration, there is another slight whine of the alternator which acts in the regenerative braking process. While the heater is in operation, there is a slight humming sound from the blower motor and blower.

MAINTENANCE

Compared to the internal combustion engine powered car, construction of the vehicle is uncomplicated. The internal combustion engine, with all its attendant parts, is replaced by a battery, an electric motor, an alternator, and a motor control panel. Maintenance of the battery consists primarily of adding distilled water to the cells every two or three months in normal operation. The electric motor and alternator can run for 3000 or 4000 hr with very little maintenance. Brushes in the electric motor should be checked every year or 10,000 miles and replaced if excessive wear is indicated. This can be done by one person in about 30 minutes. The motor control panel should not require any maintenance for the life of the vehicle, although it should be inspected periodically for possible burnt contactors.

ECONOMY

Economy of operation becomes very apparent after a few thousand miles of driving. With practically no maintenance, apart from normal brake and tire service, the only cost to contend with is the cost of electricity for recharging the batteries. The rate of fuel consumption, as indicated in Fig. 9, is 3.1-4.3 m/kw hr. Figuring the average cost of electric power to be 2¢/kw hr, and taking into consideration slight battery and charger inefficiencies in utilizing recharging current, cost per mile is less than 1 cent. Added to this is approximately another cent per mile for battery depreciation, assuming battery life to be a minimum of five years or 50,000 miles, and replacement cost to be $600.

SAFETY

Not only is the MARS II a nonpolluting vehicle, but it is also quite safe to operate. The power and accessory batteries are grounded to the frame, and protective fuses are installed between the batteries and the motor control panel and motor. Therefore, should a short circuit occur for some reason, there is no possibility that a person could be shocked from touching the frame or body of the car, since a fuse would have blown the instant the short circuit occured. Also, when the car is at rest or when it is decelerating or being recharged, the four 30 v power batteries are in parallel, so that maximum voltage exposure is always low - 30 v normally, 37-1/2 v maximum while charging.

Should a front or rear end collision occur, some of the battery containers could become cracked or broken, which would result in leakage or spillage of the sulphuric acid-cobalt electrolyte within the batteries. However, the battery compartments are outside the passenger compartment which is, in itself, sealed in a unitized body from the rest of the vehicle. Therefore, the possibility of the driver or a passenger in the vehicle coming into contact with this electrolyte as a result of a collision is remote. But should it happen, the electrolyte, being fairly dilute, would not be harmful to the skin if it were washed off with water.

The oxygen and hydrogen gases released from the batteries on charge and discharge could be explosive if concentrated in a confined area and brought in contact with a spark or flame. While the car is being driven, there is sufficient ventillation in the battery compartments to expell any such concentrations. While the batteries are being charged in a well ventillated room or garage with hood and trunk lids open, these concentrations would not occur. They could occur if hood and trunk lids were closed and charging were done in a nonventillated room. To date, no explosions have occured in any MARS II cars in service. However, should future experience so dictate, small fans could be installed in the battery compartments, which would operate while the batteries were being charged and which would eliminate any possibility of concentrations of gasses.

MARKET

The greatest potential market for a car of this nature lies with the shopper or commuter who drives less than 70 miles a day, inasmuch as the practical range of the car is 70-120 miles per charge. But, due to the rapid rechargeability of the tri-polar, lead-cobalt battery, there exists another market, a market for the commuter who travels less than 230 miles a day and who would have available to him, in addition to the on-board charger in his car, an external charging source capable of high rate charging, for example, a stationary charger with an output of 1000 amp at 40 v which might be located in a parking garage or "charging station." It would then be possible, for example, to drive 70 miles from home to office, another 70 miles during the working day, 70 additional miles from office to home, and a final 20 miles near home, after dinner. Multiple vehicle charging units located in garages, restaurants, shopping centers, or motels may become commonplace some day, just as gas stations are now.

Before high rate charging stations become generally available to the electric car public, it is likely that "plug-in" parking meters will be installed in metropolitan areas which could utilize the chargers built into electric cars. (5) In this case, the maximum driving range for some commuters might be 150 or 160 miles per day. For example, a commuter might drive 70 miles to work, plug in his car's on-board charger in a parking garage and let the batteries recharge for 8 hr, then drive another 70 miles from office to home, plug in at home, and after dinner drive another 10 or 20 miles.

CONCLUSION

An electric car has been developed that will meet the driving requirements of many residents of urban and suburban areas in terms of speed and range. Incentives for owning such a car would be that it is

1. Economical to operate
2. Comparatively free of maintenance problems
3. Quiet and pollution-free
4. Different from most other cars -- a status symbol.

However, apart from these incentives and the question of first cost, perhaps the greatest factors which might influence the prospective electric car owner would be

1. The ability of his car to be refueled rapidly in emergency situations, for example, should he forget to plug in his car's on-board charger at night.
2. The availability of rapid-recharge stations.

Referring again to Fig. 3, it can be seen that the present lead-cobalt batteries can be recharged to 80% of capacity in 46 minutes, or 40% of capacity in 23 minutes, which might satisfy the first point.

Should electric car refueling stations develop simultaneously with the development of the electric car market, for example, should future electric car dealers be required by car manufacturers to establish such refueling stations, then the second point might be satisfied as well.

It would appear then, that if the question of first cost could be resolved, a partial solution to the air pollution problem might be provided by the new electric car.

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