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L. E. Johnson

In an effort to fill an existing need two small electric service vehicles were designed, constructed, and tested. The first acted as a feasibility study and the second as a design prototype. The vehicles had low cost and the capability of being fabricated by their users as two main design goals.

The prototype design vehicle is three wheeled; utilizing a unique asymmetrical design to arrange a full length load box along one side. Motive power is provided by four automotive batteries running an electric motor. Power transmission is by a quiet gear belt drive to one rear wheel. A five solenoid switching system allows for two speeds, forward and reverse, of 5 and 10 mph. The vehicle uses motorcycle wheels and a motorcycle front fork assembly. Brakes are provided in the rear wheels. A full lighting system, consisting of headlight, tail lights, brake lights, and turn signals, is provided. Useful endurance between charges is about five hours at 10 mph. The vehicle is simple to operate and fully capable of negotiating any terrain found on the Oregon State campus.

DESIGN AND CONSTRUCTION OF A SMALL
ELECTRIC SERVICE VEHICLE

by

STEVEN CHARLES HOLT

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Associate Professor of Mechanical Engineering
in charge of major

Redacted for Privacy

Head of Department of Mechanical Engineering

Redacted for Privacy

Dean of Graduate School

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DESIGN AND CONSTRUCTION OF A LIGHT ELECTRIC SERVICE VEHICLE

I. INTRODUCTION

There exists a definite need for a small, inexpensive service vehicle in many commercial and institutional installations. At this time such vehicles are generally powered by fossil fuels, however, as the price of these fuels continues to increase and when their future availability remains in doubt, alternative methods of vehicle propulsion should be considered. In the Northwest United States the logical alternative to petroleum is electricity, because it is still rather cheap and plentiful. Thus, it was decided to design and construct a small electric service vehicle, making use of generally available subassemblies with the intention that the vehicle could be manufactured at low cost with minimum labor in minimum facilities. The general design goal was to design the vehicle for use by service personnel at Oregon State University.

Vehicle Design Requirements

The initial design requirements, as set forth in the original project proposal, were:

1) Load-capable of transporting one person and 200 pounds of tools, parts, supplies, etc.
2) Speed-up to 15 mph.
3) Range-not completely defined, but start with 15 miles as goal.
4) Grade-capable of going anywhere on Oregon State campus using streets or service roads.

5) Cost-keep as low as possible.

6) Fabrication-should be capable of being fabricated by OSU Physical Plant personnel.

Several commercially available vehicles exist which would fulfill most of the specific goals. For example, Oregon State University has three electric vehicles which they use for service related duties.

Common failings of all small electric service vehicles are poor range (compared to petroleum powered vehicles) and poor grade climbing ability - to the point that the route to be covered must be carefully planned to avoid steep hills. Also, due to the relative smallness of the industry, commercially available vehicles tend to be quite expensive. Potential design problems existed in all three of these areas and had to be considered. Most of the problems expected could be tied directly to the motor-electrical system. The motor had to be high enough in torque to propel the vehicle up steep inclines, accelerate it quickly and smoothly, and move it at design speed fully loaded, but it must draw as little current as possible, to increase the range. Also the vehicle had to be easy to operate so that it would be accepted and service personnel would use it in preference to standard gasoline powered transportation or, at least not be openly hostile towards the design.

II. FEASIBILITY STUDY

Four wheeled vehicles with a pair of driven wheels and a pair of steered wheels are attractive simply because they are the norm, but in this specific application, due to the low speed requirements, it should be possible to go to a three wheeled design. A steered front wheel allows a tiller or handlebar type steering system which would be easier and cheaper to fabricate than a steering wheel tied into two front wheels. A similar problem occurs in the power transmission from the motor to the wheels. Also because of the smaller vehicle size it should be possible to only drive one rear wheel. This would mean that no expensive and complex axle or transmission assemblies would be necessary.

Most commercially available electric vehicles use small, sometimes hard rubber, wheels. Motorcycle wheels, however, are designed to run on short, non-rotating axles, are designed to be driven easily (i.e. they are designed to have sprockets bolted to them) and have built in brakes. Also, by going to motorcycle parts, the entire steering mechanism could be adapted from a motorcycle front fork assembly. These parts are all easily available in any locality.

If motorcycle rear wheels are to be used, it would be logical to consider a chain drive from the motor to the driven rear wheel, since a motorcycle rear sprocket could be bolted onto the wheel and a front sprocket could be put onto the motor. This would save any adapting and mating problems involved in fitting some other type drive to a motorcycle wheel.

The motor itself has to be small and have low current draw but high torque, for ease of vehicle assembly, longer battery endurance and acceptable speed and hill climbing ability. Voltage requirements for the motor must bear in mind availability of batteries and the overall vehicle weight and size; since batteries could be connected as multiples of six or twelve volts and batteries weigh about 40 pounds apiece and are fairly large. Therefore, the fewer batteries needed the lower the vehicle weight and the larger the load space (for constant vehicle size). Using a 24 volt motor would need at least two 12 volt or four six volt batteries. Two 12 volt batteries would take less space and be cheaper, but might not give adequate endurance (defined as running time between battery charging).

The electrical circuitry must be simple, cheap, and efficient. Two methods of varying vehicle speed are available. First, to vary the motor rotation rate, second, to vary the wheel rotation rate by way of a transmission assembly (variable geometry slipping belt, geared transmission, etc.). Of the methods available to vary the motor rpm three are usually used in electric vehicles:

1) Rheostat-almost infinitely variable speed control possible, but consumes excessive energy.
2) Silicon Controlled Rectifier-infinitely variable and more efficient than a rheostat, but more expensive.
3) Step Voltage Control-works by changing the voltage to the motor in a series of jumps, controlled by a switch position, easy to set up, fairly cheap, and the most efficient.

A step control could be achieved with solenoids which are simple to wire up, rugged, reasonably inexpensive, and require little operating current. The solenoids could control the batteries so that the motor could receive either 12 or 24 volts--so that if the vehicle speed was 10 mph at 24 volts it would be expected to be about 5 mph at 12 volts (assuming a constant reduction between motor and wheel). If six volt batteries were used it would be fairly simple to hook up solenoids to deliver 6, 12, 18, or 24 volts but for such a low vehicle speed the convenience of the intermediary speed steps probably would not be worth the cost of the extra solenoids.

Basic vehicle size would be mostly influenced by the assumption of the most feasible alternatives for steering, motor-drive system, the necessary load space, and the requirements that the vehicle be small. To carry a 200 pound load in excess of the driver it would be necessary to include a specific load box on the order of six to eight square feet: this space must be located such that it will not interfere with the driveability of the vehicle. Also, the vehicle must be wide enough to be stable when driven. General vehicle size would be on the order of four to five feet wide and five to eight feet long. Since the design requirements call for a small vehicle it was hoped that the upper extremes could be avoided.

The vehicle frame could only really be built from two different materials, steel or aluminum. All other available materials (wood, plastic, etc.) would be too expensive, too complicated to fabricate, and/or not strong enough. For general ease of assembly and ruggedness of the finished product it was planned to make the frame from a welded construction. Aluminum is more expensive and a little harder to weld than steel so it was decided to try to use mild steel throughout the structure whenever possible.

The vehicle as originally envisioned was to be a welded steel construction mounted on three motorcycle wheels, one chain driven and one free wheeling in the rear and the other mounted in a standard motorcycle front fork assembly at the front for steering. The motor was to be controlled by solenoids and speed changes were to be accomplished by changing two 12 volt batteries from 12 to 24 volts, for two forward speeds.

From these basic ideas the MOD 1 vehicle was designed and constructed as a test of the feasibility of the design layout. The basic vehicle layout for the MOD 1 was done by John Buck (OSU Mechanical Engineering 1976) during the 1975-1976 academic year. By June 1976 he had completed the basic frame, attached the wheels, and hooked up the brakes. The remainder of the vehicle was designed and constructed by the author.

Basic Layout

The MOD 1 (See Figures 1 and 2) was a three wheeled vehicle powered by two 12 volt car batteries driving a 24 volt electric motor which turned the left rear wheel by way of a belt and chain drive system. It was 48 inches wide and 81 inches long with the front wheel in place; the frame alone was 60 inches long. The finished vehicle weighed 348 pounds, distributed with 112 pounds on the left rear wheel, 124 pounds right rear, and 112 pounds on the front wheel. The vehicle had two forward speeds--6 and 12.5 mph--and an average endurance of about four hours.

Frame

The frame of the MOD 1 was a structure of two inch square steel tubing with 0.125 inch walls welded in a trapazoidal shape and then

Figure 1. MOD 1 Left Side

Figure 2. MOD 1 Right Side

tapering in the front to a point for connecting on the front fork assembly. (See Figure 3) The rear axles were mounted on flanges welded to the bottom of the rear frame members. The front fork was supported by frame pieces fastened at the outer edge of the frame at the front and coming together at the top. A special bearing mount was fastened at this point to allow the front fork to pivot.

The seat frame was an integral part of this framework; it was fabricated as a subassembly and then welded to the main frame. The seat frame was constructed entirely of one inch angle iron, except for one upright of two inch square stock where it was felt that added strength was needed for a bearing mount. The seat framework was welded onto the center lateral frame members directly over the battery and motor mounts, which were also integral frame parts. The seat frame was 30 inches wide, 15 inches long, and 14 inches high and had a 3.25 inch wide control panel mounted along the furthest right side of the top. The sides of the seat frame were not covered.

The operator's seat was a standard "stadium" seat with a folding back that was bolted to the middle of the seat framework, directly behind the front wheel.

The motor and battery mounts were pieces of one inch angle iron welded between the center lateral frame members. The motor mounts had holds on the top sides so that the motor could be directly bolted to them. The battery mounts had cross pieces fitted to provide a well for the battery to sit into to constrain horizontal movement, but no battery hold down apparatus was included.

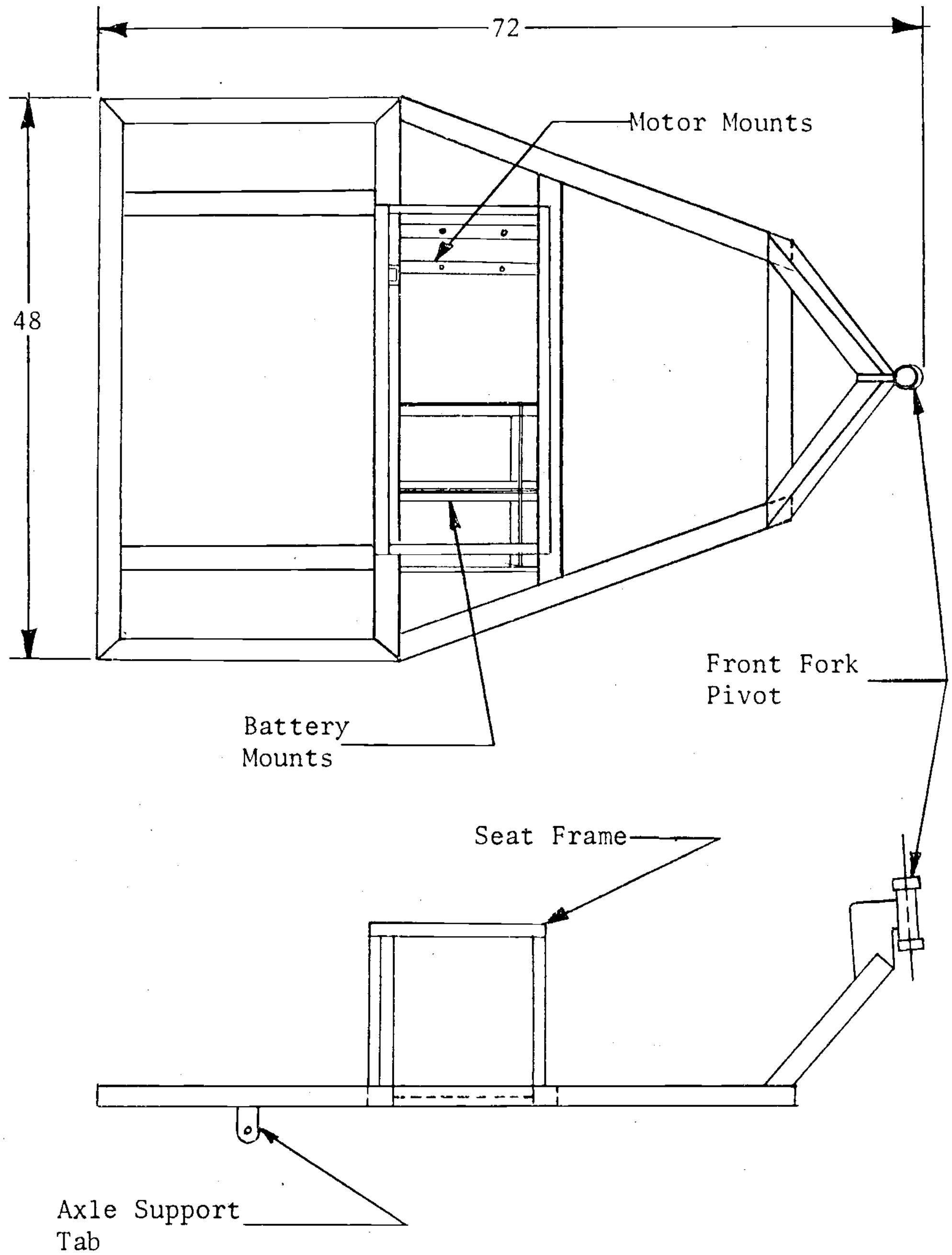

Figure 3. Frame Detail MOD 1

Wheels and Steering

Wheels used on the MOD 1 were from a Suzuki 90 motorcycle, the rear wheels being two identical 20 inch motorcycle rear wheels and the front being a standard 20 inch front wheel and Suzuki front fork assembly. The normal pivot point for the front fork assembly on the motorcycle is a bearing mount that is a permanent part of the motorcycle frame, therefore it was necessary to fabricate a bearing mounting bracket for the front fork. This was a circular pipe, 4.5 inches long, with a machined bearing support welded to each end. This support set the angle of the front fork with respect to the ground at 73 degrees.

The steering tiller bar was a piece of 0.75 inch pipe bolted to the front forks and with a T connector on the end nearest the operator with a six inch piece of pipe sticking out each side as a handle.

The left rear wheel was driven by bolting a 60 tooth motorcycle rear sprocket to the wheel hub. This is standard procedure for motorcycle drive systems and all the necessary mounting holes, in both sprocket and wheel, were already present.

Both rear wheels were mounted on their normal motorcycle axles, which were bolted through support tabs welded to the bottom of the frame. The axle centers (center of the holes in the tabs) were two inches below the frame bottom, so with 20 inch wheels the top of the frame was 14 inches off the ground.

The brake anchor arms for the rear wheels were bolted to small angle iron tabs welded to the inside of the wheel wells.

The only shock absorbing systems on the entire vehicle were the spring columns in the front fork uprights.

Motor-Drive System

The motor for the MOD 1 was a Baldor, 24 volt DC, rated at 0.8 horsepower at 33 amps and at 2600 rpm. Design vehicle speed was to be about 10 mph so a reduction of about 15 to 1 was needed for 20 inch wheels. This was accomplished by a 3:1 step down from the motor to a jack shaft and a 5:1 reduction from the jack shaft to the wheel. The first step down, from the motor to the jack shaft, was done with a B section V belt, running from a 2.375 inch diameter pulley on the motor output shaft to a seven inch diameter pulley on the jack shaft. The actual ratio of motor and jack shaft rotations then was 2.95:1, giving the shaft 881 rpm rotation rate. A 12 tooth motorcycle drive sprocket was fastened to the other end of the jack shaft and this drove a 60 tooth sprocket bolted to the rear wheel with a standard motorcycle chain. (See Figure 4) This gave an overall reduction of 14.75:1, or the driven wheel would run at 176 rmp for a motor rotation of 2600 rpm.

The jack shaft was mounted on the rear side of the back seat frame uprights by two FAFNIR RAK 3/4 inch bearings positioned on the jack shaft inboard of the pulley and sprocket. The pulley was on the extreme right side of the shaft, the sprocket was on the extreme left side and the bearings were between. The motor was mounted with its output shaft pointed inward.

Proper belt and chain tension was supplied by positioning the motor, with slots in the motor base plate, and by varying the mounting position of the jack shaft by shimming the bearing mounts with washers.

Since the jack shaft was mounted on the rear side of the seat framework a plywood cover box was built over it to prevent anything on

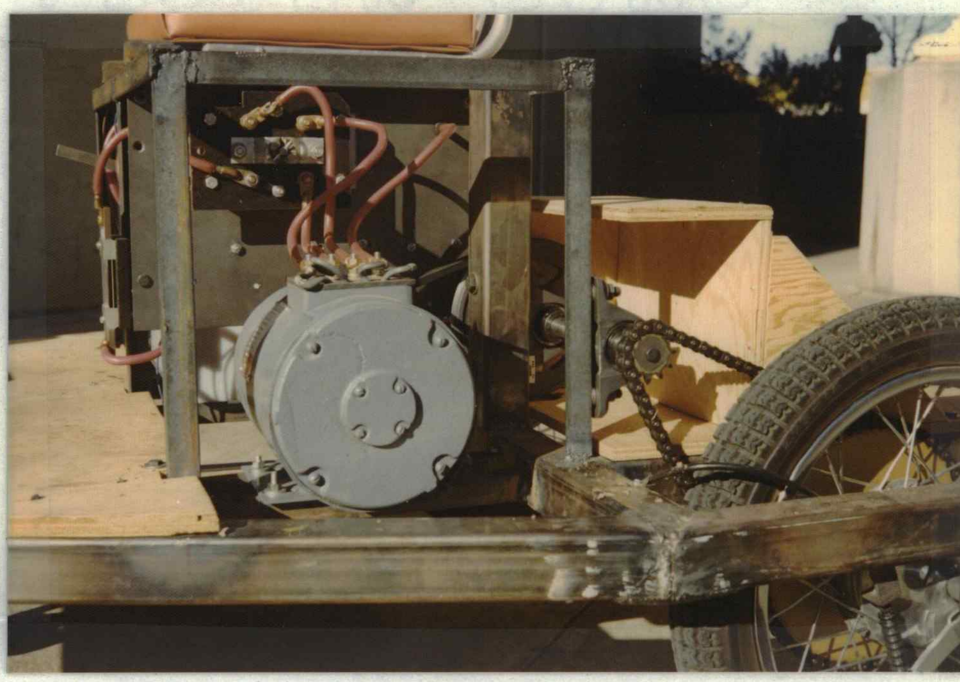

Figure 4. Motor and Drive MOD 1

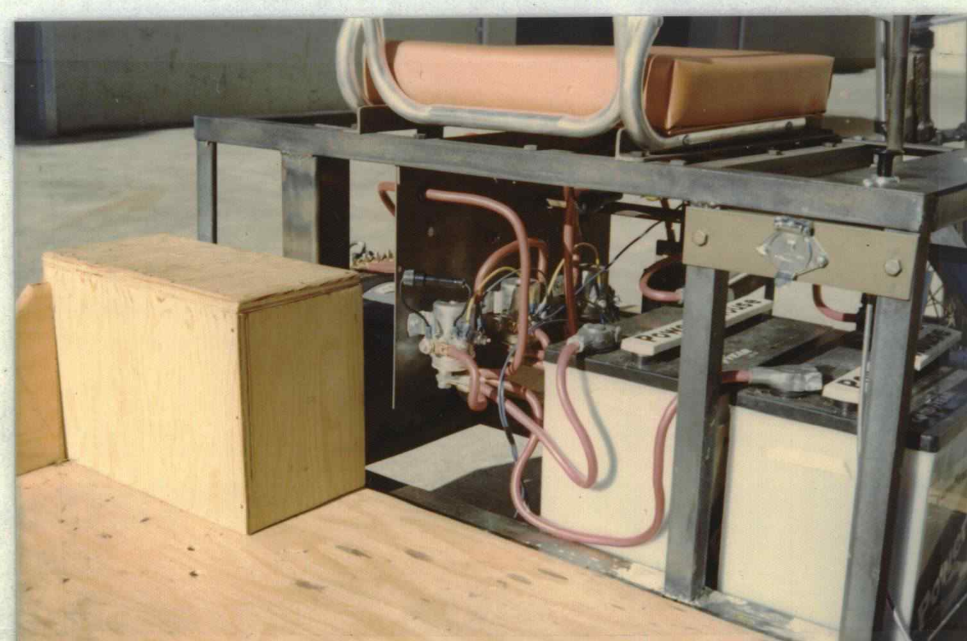

Figure 5. Electrical System and Cargo Deck MOD 1

the rear deck from slipping into the drive system. (See Figure 5)

Electrical System

The electrical system of the MOD 1 consisted of three 12 volt solenoids (two double pole, single throw and one single pole, single throw). One acted as a master control unit and the other two controlled the speed changes. Also there was a manually operated forward-reversing switch and auxiliary and safety systems. Electrical power was provided by two Goodyear Powerhouse 12 volt batteries rated at 88 amp-hrs. (See Figure A-6.)

The speed control used two single pole, double throw solenoids to change the battery circuit from parallel (12 volts) to series (24 volts), and thereby change the motor rotation rate. The solenoid normally closed position provided 12 volts and the normally open position provided 24 volts. The solenoids were activated by two microswitches fastened to a foot lever such that, when the first switch was activated the main power solenoid activated, causing current to flow to the motor at 12 volts. When the second microswitch was activated the two other solenoids would activate and the motor voltage would increase to 24 volts.

The forward-reversing mechanism was a three position, manually operated, rotary switch which allowed the motor armature current direction to remain constant but reversed the direction of the field current and thereby the motor rotation direction. The intermediary switch position provided a neutral and, since the motor would not drive the vehicle with the switch in this position, it provided another safety feature.

Safety interlock systems in the solenoid control circuitry were provided such that a key switch had to be on for the system to energize and a microswitch in series with the key switch also had to be closed for the motor to operate. The microswitch was held in the closed position by a tab on the brake activation rod. If the brakes were activated the tab would move away, opening the switch, deactivating the control solenoids and disconnecting the motor from the batteries.

Power for the control system was taken off one of the batteries. Each of these control wires had a 20 amp cartridge fuse mounted in both the positive and negative ends (at the battery terminals). An emergency disconnect switch was connected across the positive lead of both batteries so that if a short or other electrical problem occurred, all electrical power could be turned off manually. Each positive lead also had a 60 amp fuse mounted in it at the disconnect switch.

The only auxiliary electrical system mounted on the MOD 1 was a standard 12 volt automobile horn activated through the control system circuitry and controlled with a push button switch on the control panel.

The mechanical forward-reversing switch and the three solenoids were vertically mounted on a plate below the left side of the seat so that they divided the seat framework between the motor and the batteries. (See Figure 5.) All wiring was on the battery side of this mounting plate, except for the wires going directly to the motor. Large battery cables were used for the power circuitry and 16 gauge twisted strand insulated wire was used for the control circuitry. All connections used crimp-on lugs, and wires were bundled when feasible.

The mechanical disconnect switch was mounted directly under the right side of the operator's seat so that its operating lever stuck out forward, just under the operator's right leg, for ease of operation.

The key switch and horn button were mounted on a thin steel control panel on the right side of the seat framework and the forward and reversing lever was mounted in a slot between the control panel and the operator's seat; it was linked to the switch itself (mounted on the solenoid panel) by a 15 inch rod that extended under the seat.

The horn was mounted to a piece of insulating board, which in turn was bolted to the underside of the frame. This was necessary since the frame was not grounded.

Pedals and Linkages

Brakes. The brake system consisted of the drum brakes that came in the motorcycle rear wheels. Motorcycle brake cables ran from the rear wheels to an activation bracket under the rear side of the seat framework. Since the two brakes must activate evenly a swivelling bar was hooked to the two brake cables and fastened in the middle to the main brake activation rod so that when the brake pedal was pushed an even tension would be maintained in each brake cable and the vehicle would stop smoothly.

The brake pedal was mounted to pivot at the bottom (under the floor board) and the brake activation rod was swivel mounted above this pivot point so that a forward push on the brake by the operator caused the brake activation rod to be pulled forward and the brakes applied when this motion put tension on the brake cables.

A mechanical parking brake was developed by fastening a pivoting yoke bar to an automotive type choke cable so that if the cable was pulled when the brakes were activated, the yoke would slip over the brake activation rod pivot bar and the brakes would be held forward in an activated position. The cable control knob was mounted on the extreme rear end of the control panel. The use of the brake in this way also activated the brake safety switch so that the motor would not operate while the parking brake was on.

Speed Control. The speed control mechanism was a system of two microswitches mounted in conjunction with a foot pedal and a series of three springs and a supplementary lever. When the foot pedal was pushed it would activate the first switch by putting tension on a strip of metal mounted over it, which would depress the switch. Further foot pressure would cause the lever to come in contact with the supplementary lever, which was held in place by a very strong return spring (spring constant about 40 pounds per inch). This would cause a definite feedback so the operator could drive the vehicle in low by resting his foot at this step. Pressure beyond this point would cause the supplementary lever to close the second microswitch. It would then come up against a stop so that the switches could not be over stressed. This mechanism was mounted on the outside of a 0.25 x 2 x 2 inch piece of angle iron six inches long. This was bolted to the bottom of the floorboard, to the right side of the brake pedal assembly.

Testing Procedure

There were two basic performance areas to be tested in the vehicle: the electrical system and the vehicle driveability. The electrical tests attempted to determine the current draw in the system for differing load conditions and the system response to different driving and use situations. The driveability tests tried to determine if the vehicle was a stable platform capable of meeting the design requirements for speed, endurance, load, and terrain accessibility.

To measure the current draw in the system under driving conditions a 100 amp at 50 mv shunt was placed in the line between the master solenoid and motor terminal A1 (Armature terminal). A chart recorder was hooked across this shunt and, although it read out voltage, the known resistance of the shunt allowed this reading to be immediately converted to the current draw. This provided a permanent log of the current in the system with respect to time. (See Figure A-8)

To obtain repeatable data to correlate, a set course was run which included various types of terrain expected to be encountered in service. This course ran out the basement doors of Rogers Hall (east side), once around the parking lot, and out to Campus Way by way of the east side of Covell Hall. There the route followed Campus Way to the east and turned to the right up the road that circled Benton Hall. It followed this road down past Milne Hall and then retraced the route along Covell, through the parking lot, and back into Rogers. Total length of this run was about 3300 feet.

Different current transient responses were tested by measuring the effect on the current of switching the vehicle into reverse while moving forward and vice versa, of starting up when stopped on a hill, and other general driving conditions.

Various tests were run to determine the vehicle response to different terrain features and operator demands. The only exterior test equipment used was a "fifth wheel" set up to measure the vehicle speed. (See Figure 6.) This was a trailing wheel that was attached to the

Figure 6. MOD 1 Undergoing Speed Tests

rear bumper.

Tests run included top speed in many situations of load and grade, steering response in low and high, forward and reverse, cornering capability, and ability to drive on pavement, gravel, sand, grass, and any other terrain discovered during driving tests. An estimate of the steering capability was determined by measuring the diameter of the smallest circle about which the vehicle could turn.

Rather than a set data taking procedure most of these driving tests were the operators' and/or passengers' opinions of the drive and overall feel of the vehicle.

Results--Electric. The first series of current ratings were attained in a no load condition. This was done by raising the driven wheel off the ground so that it could spin freely when the motor was energized.

No load tests for the MOD 1 showed a steady state current draw in low of 16 amps and in high of 17 amps. Any increase in the voltage (off to low, low to high, or off to high) caused a higher transient current draw. Average off to low transient was 37 amps, from low to high was 31 amps, and from off to high was 36 amps. All of these transients would die out to steady state values within about 3.5 seconds.

Operator only tests for the Benton Hall Circuit showed that the maximum steady current needed to climb the hill on the route to be 36 amps. Least power (motor on) was needed when going down hill, this being 20 amps. (See sample chart in Appendix). Normal transients encountered when starting in an actual driving condition were about 60 amps when the motor was warmed up and about 80 amps when the motor was first started. Highest transients were encountered by starting from a stop on a hill, the highest recorded being 90 amps. On long runs of more than two or three minutes on level ground the vehicle steadied at 26 amps.

Results-Driveability. Fifth wheel tests showed the top speed to be about 12 mph on level ground with one operator and no additional load. This speed would drop to about 5 mph while climbing a steep hill. The speed in low was half the top speed. Speeds in reverse were identical to forward speeds. Each passenger or 150 additional pound load tended to slow the vehicle by about one to one and a half miles per hour, up to four such loads, the maximum tested. Acceleration was fast and the vehicle could reach top speed in about three seconds.

Steering was quick and responsive at all times and tiller bar pressure was light and manageable. This meant, however, that the vehicle could only be operated "hands off" for short periods of time or the uneveness of the terrain would cause it to change course.

The vehicle tended to diverge from a straight path and veer to the right when it was started up on a smooth or loose surface. This was encountered especially in sand and, to a lesser degree, in loose gravel. If the vehicle traversed a smooth or loose surface while moving no such steering problem was encountered.

Due to the drive system set up there were two speeds forward and reverse and, while the vehicle was stable in forward, it tended to fishtail when in high speed reverse. This could get severe enough to be potentially dangerous to inexperienced operators running the vehicle for the first time. This instability caused at least one accident when an inexperienced driver fell off the vehicle while making a high speed turn in reverse; but, as driver experience increased the vehicle became very easy to control and the chance of an accident decreased.

The braking system provided few problems. Stopping distance depended almost entirely on operator comfort, that is, the brakes were capable of bringing the vehicle to a halt in a distance dependent on operator foot pressure, but this also caused a correspondingly high inertial load on the operator, load and passengers.

The MOD 1 had a very small turning radius and could easily be turned around in a narrow street without going onto the curbs. The smallest circle that it could turn about depended heavily on whether it was a curve to the left or to the right, those to the right being much smaller. To the right the MOD 1 could turn about a one foot diameter circle and to the left it could turn about a five foot circle. The limitations on the turns to the left were the physical turning limitations of the front fork assembly in low speed, but in high speed turns to the left a point near the physical limitation would be reached at which time the front wheel would "skitter" or jump along instead of rolling smoothly. This was caused by the wheel being turned so that it was acting mostly in a direction perpendicular to the driven wheel and if this limit was exceeded the front forks would be pulled over all the way to the left. This caused the front wheel to roll very little and the motor would expend its power attempting to push the front wheel sideways. This situation was seldom encountered during normal driving since it could only come about when making a fully locked left turn at high speed.

Off road capability was not one of the design requirements of the vehicle but it was remarkably capable of traversing many different ground features. Aside from the steering problems associated with starting on loose surfaces, the vehicle seemed to be able to move over pavement, gravel, sand, rock, short grass, or dirt with ease. The higher the rolling resistance, as in grass, the lower the speed, but the vehicle never bogged down entirely due to the type of surface on which it was moving.

The MOD 1 had little problem going up or down curbs in the height range of seven to eight inches; if the operator approached them at a very low speed and only applied power after the front wheel came in contact with the obstacle. The vehicle would bottom out climbing a seven inch high obstacle if it was any shorter than two feet. The limitation was the lowest point of the brake assembly and if the obstacle was longer than two feet no problem was encountered.

Approximately 30 people have operated or attempted to operate the MOD 1 and their performance and opinions were noted closely. The vehicle had a generally triangular shape in the front, so that to the inexperienced driver the total vehicle width appeared to be about as wide as his or her knees (i.e. about 18-20 inches) when seated in the operator's seat. This caused many people to turn too close to the inside of corners or to try to fit the vehicle through a gap that was too small for it to fit through. Both of those situations risked a collision between the side frame and the obstacle. This same situation also appeared several times when travelling in a straight line when the vehicle was forced to one side of the road or path to avoid another vehicle or some other obstacle, and the operator ran the side frame into the curb. Such collisions were of little consequence in the MOD 1 due to the triangular shape since the vehicle would simply bounce off whatever it hit and there were no corners for it to hang up on.

With the driver's seat directly in the middle the operator had trouble relating the positions of both the rear corners while backing up, this, coupled with the steering instability in reverse, made backing collisions a definite possibility.

Many operators felt that the steering response of the MOD 1 was too fast and that the vehicle was unstable. This opinion was not entirely shared by those operators with the most driving time, who felt that the vehicle was easy to drive, would react quickly and accurately to almost any steering demand, and was, in general, enjoyable to drive.

The majority of the operators thought that the vehicle speed was about right for campus-like applications in which there would always be many pedestrians and bicycles, as well as cars, to contend with and any faster speed would not be safe.

The control system was very simplistic and only a 30 second explanation was necessary for most operators to comprehend vehicle operation, although about 20 to 30 minutes of driving time appeared to be required to really become familiar with the vehicle driving characteristics.

Discussion of Feasibility

The construction and tests on the MOD 1 showed it to be a successful basic vehicle; they showed that a three wheeled electric service vehicle could be built and get good performance with one driven wheel. But it also showed several specific details that should be changed on a vehicle redesign.

The frame of the MOD 1 was difficult to fabricate because of the type of material and the shape of the frame with its difficult and necessarily precise angles to cut and weld together. An easier method was needed, although the frame definitely was strong enough. The wooden floorboards became gouged, chipped, and stained easily and needed to be replaced with something more durable and waterproof. The steel frame itself became considerably stained with battery acid, since the battery supports were part of the frame and no protective covering was over the batteries. They needed some type of box to sit in to cure this problem. The method of fastening the rear axles to the frame by tabs provided a weak point in the structure and the tabs would probably have been one of the first things to break in an overload condition, especially one due to a lateral load.

The initial fork angle on the preliminary design was 60 degrees with respect to the ground. This resulted in severe vehicle instability and to drive the MOD 1 in this configuration it was necessary to keep tight control of the tiller bar at all times. If the tiller were released even for an instant the entire front fork would slam into a fully locked position to the left or right. It would also tend to go into a fully locked position when driving if the operator attempted to turn a very sharp corner. The situation was annoying and potentially dangerous at all times. The problem was solved in th MOD 1 by increasing the fork angle to 73 degrees, which resulted in a much stabler vehicle that was much safer and easier to drive.

The chain drive system was the noisiest part of the MOD 1 and it would throw oil and dirt that it had picked up against the vehicle. A quieter, cleaner drive system was desirable.

The pipe tiller bar was fully functional and very convenient to assemble, but it was decided that the handle assembly on the final design should be rounded so that the operator would be less apt to be injured if he collided with the handle in an abrupt stop or accident.

Since the parking brake was entirely below the floorboards there was not always any indication that it had activated. Also it was not a positive locking system, the yoke arm could slip off the brake rod and the brakes could release. A better, simpler, and easier to see system was needed on the final design.

III. VEHICLE REDESIGN

From the examinations of the MOD 1 test results it was seen that the basic vehicle was successful and met or exceeded all (modified) design requirements, but that some changes could be made. Additional comments by prospective users caused two more design requirements to be added for the final design. These were the desire for a full length load box and to put in four batteries for increased endurance.

To fit the load box onto the vehicle it was decided to design the second vehicle asymmetrically, with the load space on the right and the motor-drive system on the left.

After some consideration of other structural members for use in the frame (square, circular, C channel, and angle iron) it was decided that probably the easiest to build and cheapest frame could be built of bar stock with a thin plate welded onto the top for torsional rigidity, if a strength analysis allowed. Calculations (See Appendix) showed that the method was feasible and it was decided to try this frame design. While it would have produced a lighter vehicle if the frame could have been made of aluminum, costs prohibited this and steel was used throughout. (Aluminum frame--50 pounds, $300; Steel frame--110 pounds, $40. Based on price quotes from Physical Plant, OSU and Pacific Metals Company, Portland, Oregon.)

To quiet the vehicle down it was decided to go to a gear belt drive system from the jack shaft to the left rear wheel. This system is a toothed belt that meshes with a toothed pulley. It was expected that the system would include the quiet operation of a V belt with some of the non-slip properties of a chain.

The decision to go to four batteries meant that the seat frame had to be made larger to fit everything underneath it. The design chosen called for the batteries in an "L" shaped battery box to the right side of the motor, such that the furthest right side of the seat frame was 26 inches in from the left side of the vehicle. This dimension was minimized so that the load space could be made as wide as possible.

Since the basic design was shown to be feasible by the MOD 1 the second vehicle could include some added design features that would be expected on a more production oriented vehicle, such as expanded safety systems and a full lighting circuit.

Design Details MOD 2

Basic Layout

The resulting MOD 2 vehicle (See Figures 7, 8, and 9) was slower and heavier than the MOD 1; top speed was 10.5 mph and it weighed 523 pounds without an operator or load. Weight distribution was 202 pounds left rear, 146 pounds right rear, and 175 pounds on the front wheel. A combination of a gear belt drive system and a totally enclosed motor and drive system made the vehicle very quiet in operation.

Total endurance of the MOD 2 was on the order of eight hours, however, this time was highly dependent on the type of terrain on which the vehicle travelled. After five hours of travel time the vehicle lost almost all of its hill climbing ability. The endurance decreased with increased load and surface rolling resistance.

Frame

The MOD 2 frame was built up of steel bar stock covered with a 12 gauge (0.106 inch) steel plate. (See Figures 10, 11, and 12.) It

Figure 7. Overview of Complete Vehicle MOD 2

Figure 8. MOD 2 Left Side

Figure 9. MOD 2 Right Side

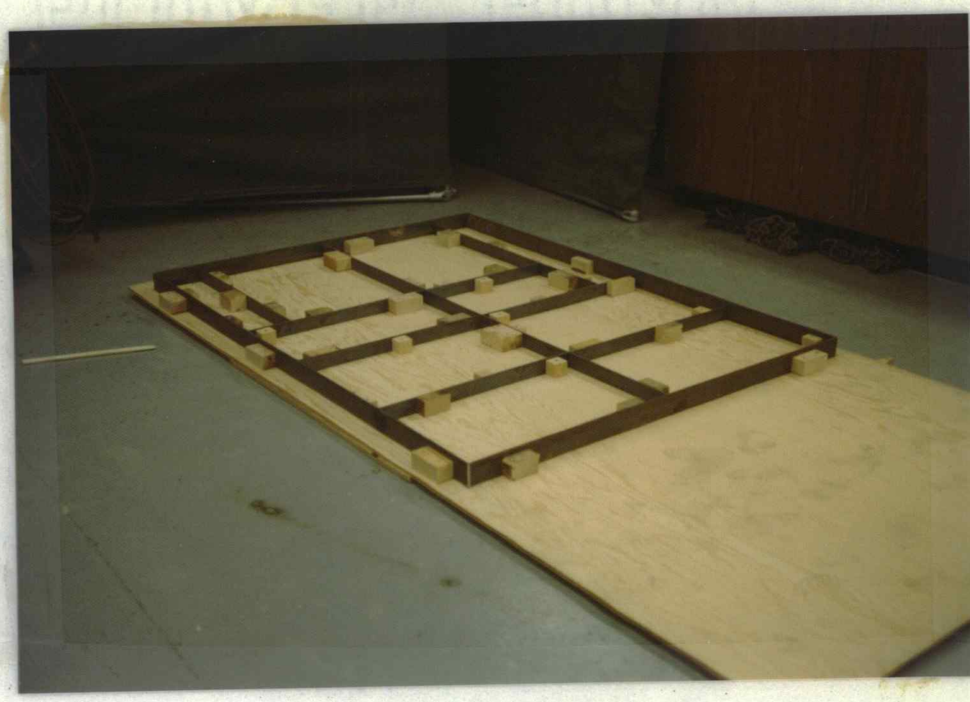

Figure 10. Basic Frame on Jig During Construction MOD 2

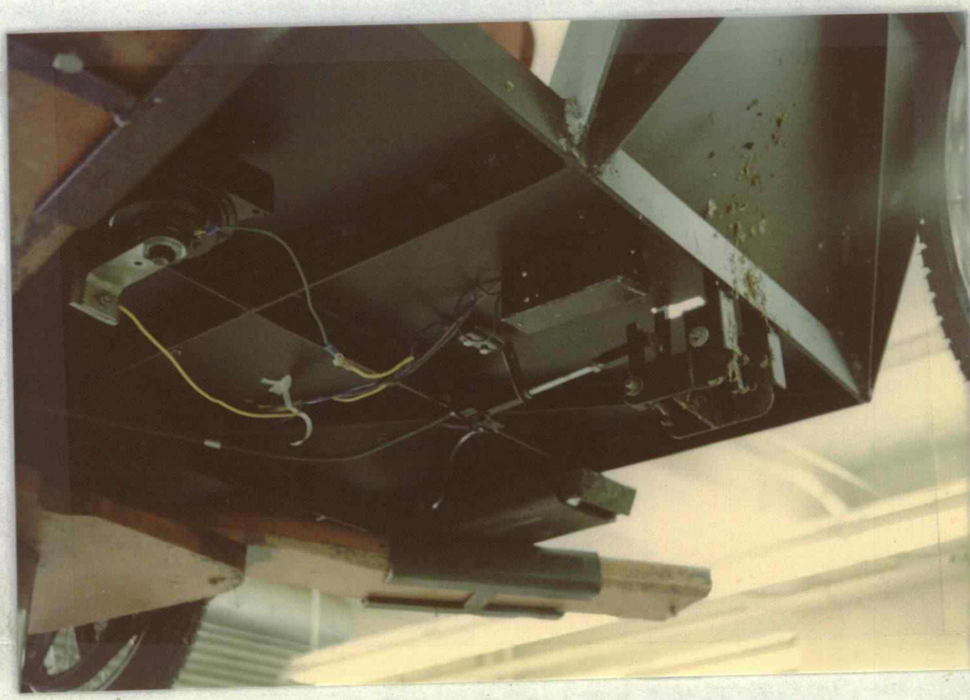

Figure 11. Frame From Below MOD 2

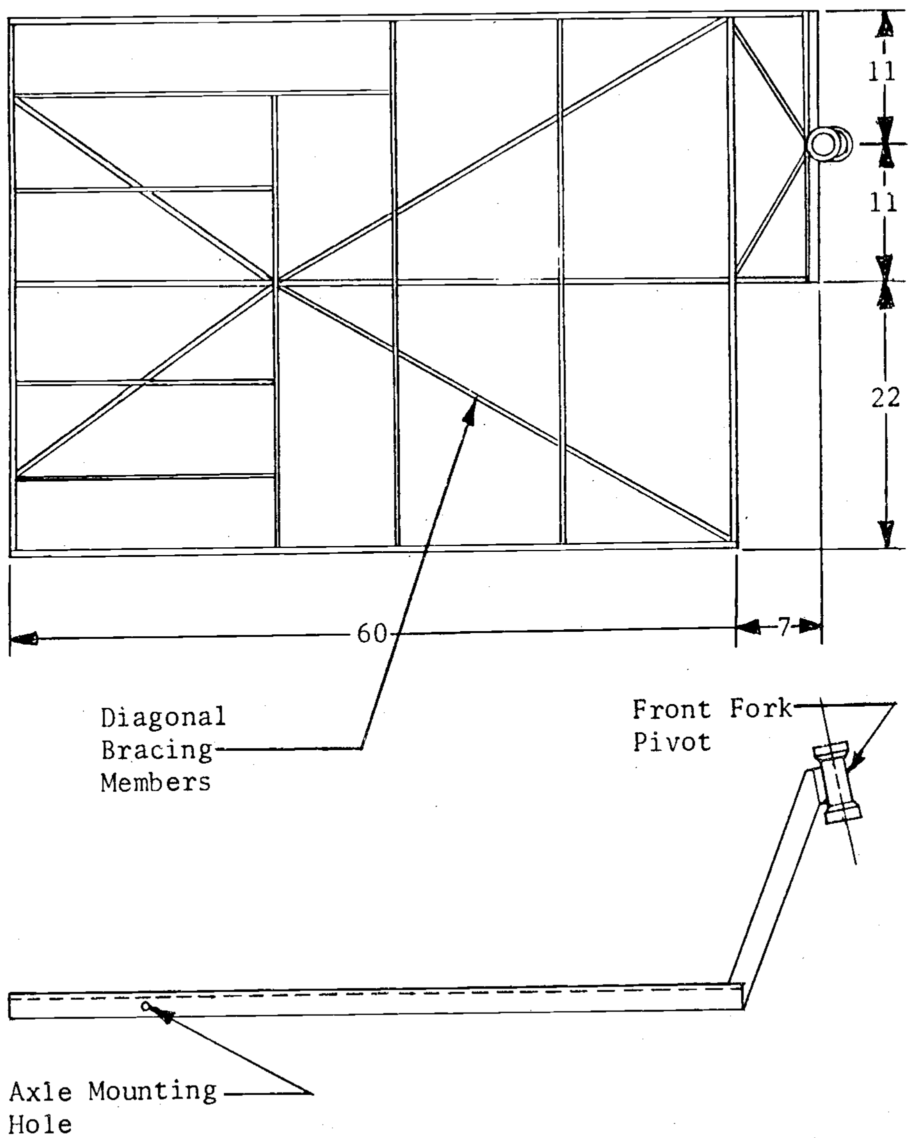

Figure 12. Frame Detail MOD 2

was rectangular, 44 inches by 60 inches, with the seat and the front wheel being mounted asymmetrically to the left side. Overall length including the front wheel was 84 inches (seven feet). The bar stock framework of the wheel wells was different on the left and right sides to allow room for the drive pulleys and belts on the left side.

The frame included three different sizes of bar stock. The outer edges were of 0.25 x 2 inch stock, the inside rectangularly mounted members were 0.1875 x 1.5 inch stock, and the diagonal bracing members were 0.125 x 1 inch stock. Defining the frame without the bracing members as the basic frame, all basic frame members had the same bottom plane, that is, all the inner members were set down 0.5 inch with respect to the outer four sides. The plate was welded onto the basic frame inside the outer four edges so that a 0.394 inch lip was on all four sides of the vehicle. The only appendage to this framework was the front fork support system. This was a 22 inch wide rectangular subassembly of 0.25 x 2 inch bar stock with a 21.75 x 18 inch plate welded to it and two 0.1875 x 1.5 inch pieces of stock as diagonal bracing members on the front. This assembly stuck out from the front of the vehicle at a 70 degree angle with respect to the floor plate.

The rear axles went through holes drilled directly into the frame members on each side of the wheel wells at a point 0.75 inch up from the bottom of the basic frame. Then, with 20 inch wheels, the top of the frame was 11.25 inches off the ground.

Both the rear wheels were entirely covered by 22 gauge galvanized steel fenders. The right fender was self supporting and complete, the left fender fastened into the extreme left side of the seat framework.

Each fender was fastened to the frame or floor plate with machine screws.

The seat frame was a bolt on subassembly held on by seven 1/4 NF bolts through the floor plate (front and rear sides) and the side member (left side). The seat frame was welded one inch angle iron covered by thin sheet metal. It was 25.75 inches wide, 23 inches long, and 14.5 inches high. The top of the frame was of two parts, a six inch wide steel control panel along the extreme right side and a 19.75 inch wide steel seat base plate mounted by hinges at the rear of the seat frame and with a lip hanging over the front edge. The operator's seat itself was screwed directly to this plate. The right side seat frame side panel was riveted to the seat frame, the other three sides were attached with sheet metal screws, for ease of disassembly, if necessary.

The operator's seat was fabricated by fastening plasticized cloth (vinyl) over foam rubber set on a piece of plywood. The back support plate was made with the same method and was held up by two pieces of 0.1875 x 1.5 inch bar stock bent at a 90 degree angle directly behind the main seat and screwed into both the main seat and the back support.

Wheels and Steering

The wheels and front fork assembly used on the MOD 2 were from a Suzuki 90 motorcycle (same as used for the MOD 1). Wheel diameter was 20 inches. The front wheel was 8.5 inches to the right side of the driven rear wheel.

The front fork pivot assembly was a 4.5 inch long piece of two inch square tubing with one inch thick bearing races welded to each end. (See Figure 13.) It was welded to the center of the front fork support member, 11 inches in from the left side and so that the front forks

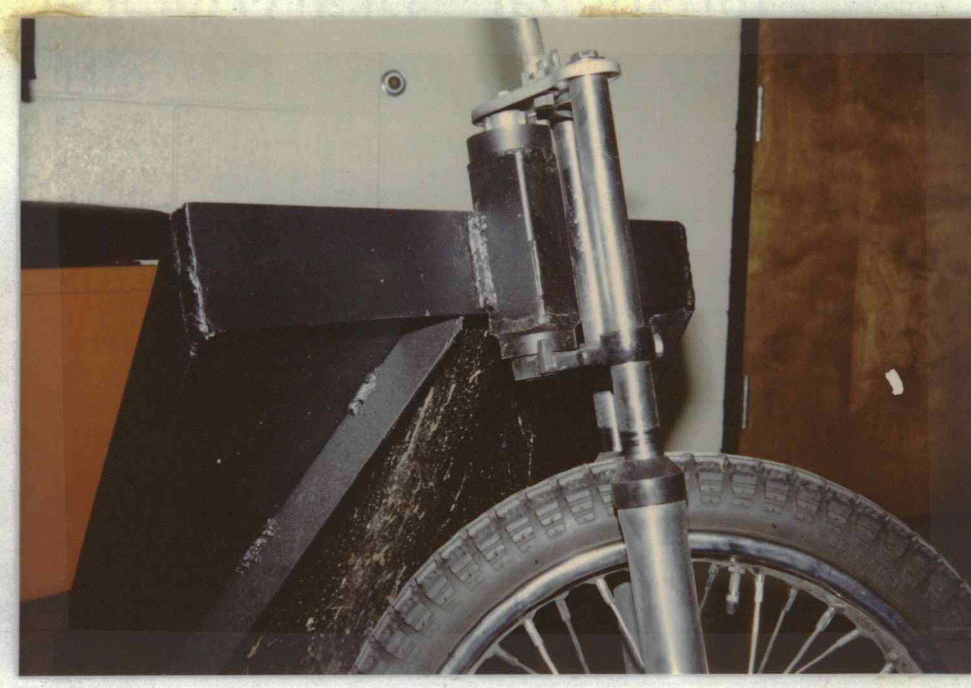

Figure 13. Front Fork Pivot Point MOD 2

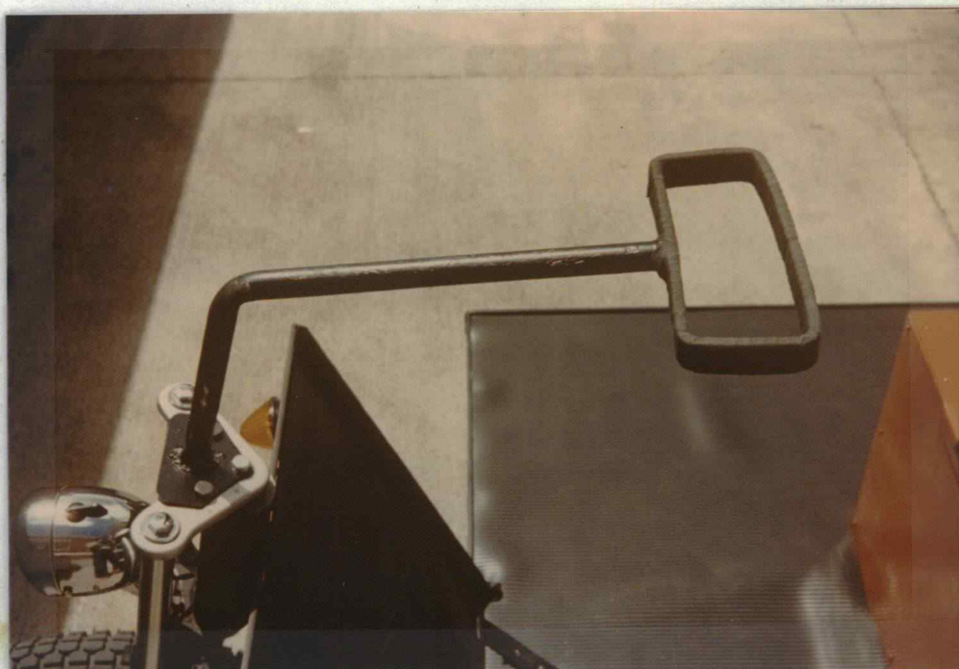

Figure 14. Tiller Bar and Front Fork MOD 2

would be at an angle of 78 degrees with respect to the ground.

The steering tiller bar was a piece of 0.75 inch diameter pipe 19 inches long that was bolted to the top of the front fork, rose up seven inches and then was bent back toward the operator. (See Figure 14.) The actual control handle was made from a piece of 0.25 x 1 inch bar stock 25 inches long bent into a rectangle, 3.5 x 9 inches. This handle was wrapped with bicycle handlebar tape. The rearmost part of the handle was 10 inches forward of the front edge of the operator's seat.

The left rear wheel was driven by a gear belt pulley. The pulley was bolted to a steel adapter plate which was bolted to the wheel. The hub of the gearbelt pulley was machined so that it fit over the large interior hub of the wheel with their inboard faces flush. The adapter plate was fitted against this surface and bolted to the wheel using existing sprocket mounting holes and to the pulley through three holes drilled and tapped in the pulley hub. The right rear wheel was free wheeling.

The brake anchor arms were bolted directly to the outside frame pieces on each side.

The only shock absorbing system in the vehicle was that provided by the spring columns of the front fork uprights.

Motor-Drive System

The MOD 2 used the same 24 volt Baldor motor as the MOD 1 and used the same initial step down system between the motor output shaft and the jack shaft-a B section V belt with a 2.95:1 reduction ratio. (See Figures 15, 16, and 18.) From the jack shaft a Browning gear belt was used to turn the driven wheel. A Browning 17 tooth pulley (17HB100) was

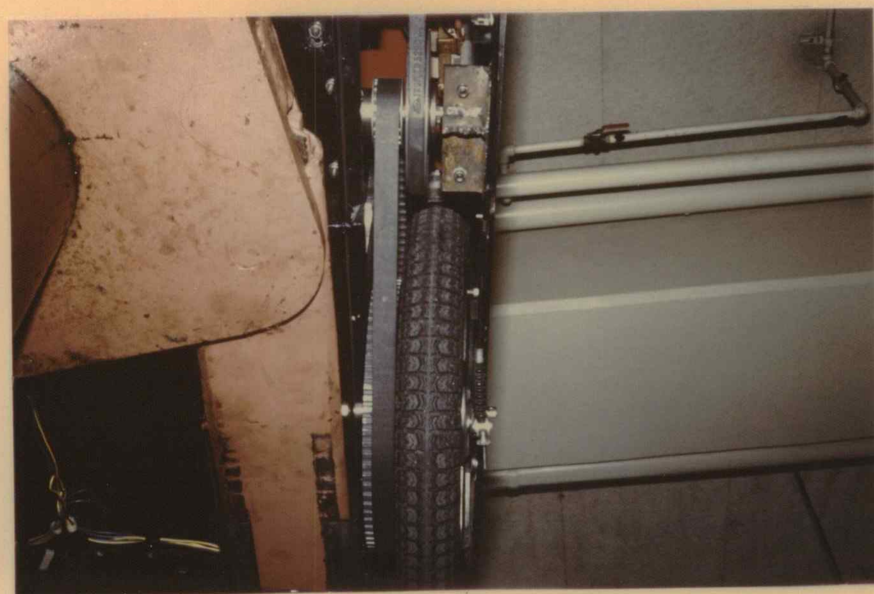

Figure 15. Drive System From Below MOD 2

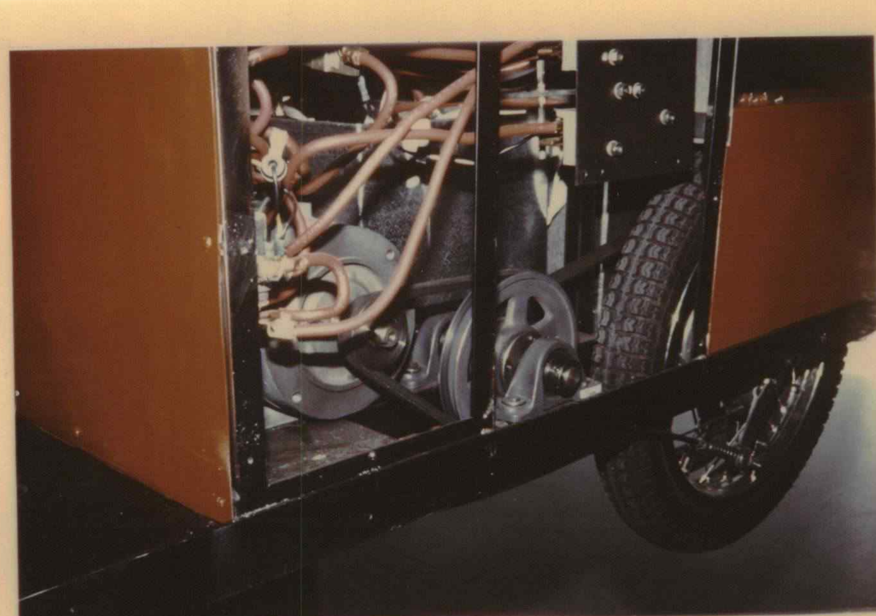

Figure 16. Drive System From Side MOD 2

mounted to the jack shaft and an 84 tooth pulley (84HB100) was modified to fit the rear wheel. A one inch wide gear belt (D570H100) ran between them. This system gave a step down ratio of 4.94:1, so the overall reduction was 14.56:1. When the motor was at 2600 rpm the output rotation of the wheel was 179 rpm; producing a speed of 10.6 mph with 20 inch wheels.

The right jack shaft bearing (FAFNIR RAK 3/4) was bolted to the floor plate, the left bearing was bolted to a 0.25 x 2 x 2 inch piece of angle iron five inches long welded to the outer frame member inside the left wheel well. The total shaft length was 7.5 inches and diameter was 0.75 inches, with the bearings being on the extreme ends and the seven inch V belt pulley and the gear belt drive gear being side by side in the middle of the shaft, with the pulley on the left side.

The motor was bolted directly to the floor plate with the output shaft pointed to the left side. Proper belt tension was maintained by positioning the motor and the bearings by means of slots cut in their respective mounting plates.

The jack shaft and gear belt drive systems were mounted directly under the seat frame as nearly level with the floor plate as possible so they were entirely covered by the seat frame and left fender and no additional protective covering was necessary.

Electrical System

The electrical system of the MOD 2 consisted of five solenoids; (four double pole, single throw and one single pole, single throw) one was a master solenoid, two operated the speed control and the remaining two controlled the forward-reversing circuit. In addition there were the safety and auxiliary systems. Electrical power was supplied by four 12 volt Goodyear Powerhouse batteries, each rated at 88 amp-hrs, connected into two battery packs, each pack containing two batteries wired in parallel. (See Figures 17, 18, and A-7.)

Vehicle speed was controlled by changing the motor input voltage from 0 to 12 to 24 volts. This was the same three solenoid system that was used in the MOD 1. When the first foot pedal activated micro-switch was closed it closed the master solenoid at which time the vehicle ran in low, since the parallel (12 volt) circuit was connected through the normally closed solenoid positions. When the second micro-switch was activated both of the double pole, single throw solenoids activated, which changed the battery packs to series and ran 24 volts through the motor.

The forward and reversing action was controlled by two solenoids controlled by a hand operated toggle switch. The solenoids controlled the direction of current flow through the field coils (shunt) in the motor, and thereby the direction of the rotation. The forward mode was wired into the normally closed position, so the vehicle required no additional energy to run in forward. However, when the toggle switch was placed in the reverse position both solenoids activated and stayed activated as long as the switch was in the reverse position. In high speed reverse all five solenoids would be activated.

There were six safety systems built into the MOD 2. In order to provide control circuit power it was necessary to overcome five possible open circuit points in the main control power wire. A key switch had to be turned on and the operator had to sit on the operator's seat to

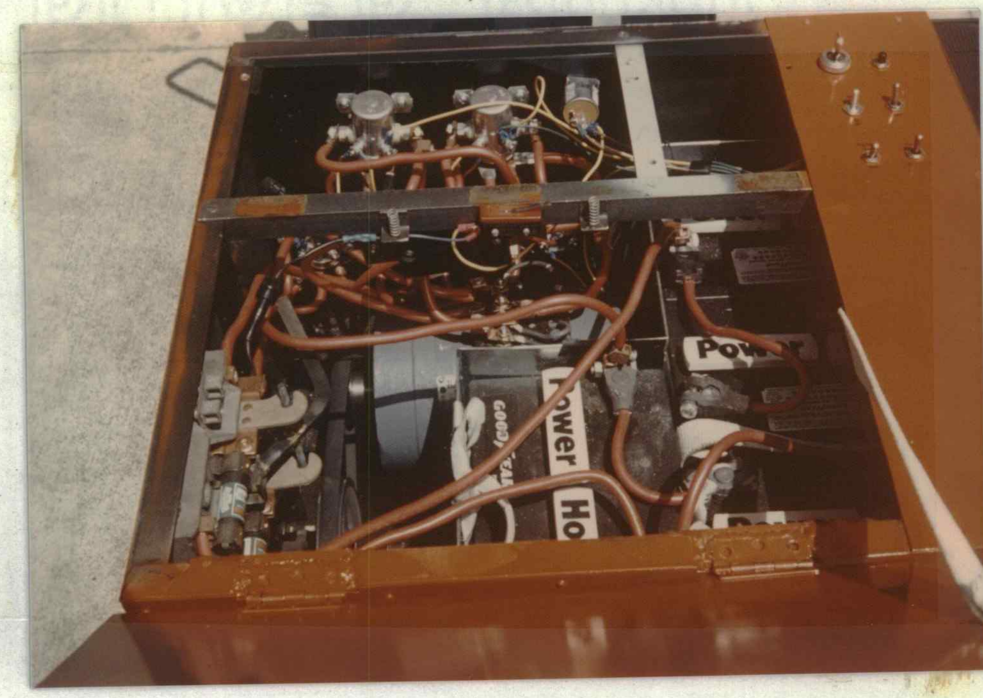

Figure 17. Electrical System From Behind MOD 2

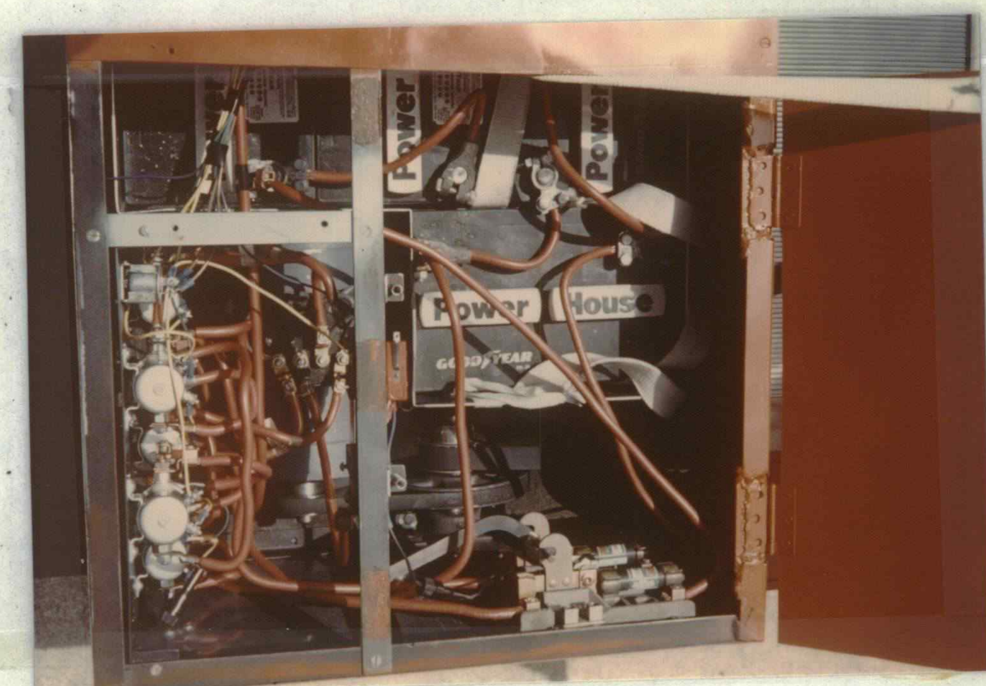

Figure 18. Electrical System From Side MOD 2

energize a switch installed under the seat base plate (this switch was activated by a force of approximately 10 pounds acting on the seat). Also on this line was the brake activated microswitch. This switch was wired in a normally open position but was held closed by a tab on the brake activation rod when the brakes were not in use (See Figure 11). If the brakes were applied this circuit was opened and power to the solenoid control system was lost. A total of four fuses were in the electrical system, one 20 amp fuse on each end of the solenoid control circuit power wire and one 60 amp fuse on each of the positive leads coming from the battery packs. Each battery pack positive lead went through a master disconnect knife switch to allow the operator to manually remove power from the system. The disconnect did not disconnect the battery packs themselves into two separate batteries, but only unhooked the battery packs from the rest of the circuit.

Auxiliary electrical systems in the MOD 2 were the horn and the lighting systems. The horn was a standard 12 volt car horn operated by a pushbutton switch mounted on the control panel. Three lighting systems were present: brake lights, running lights and turn signals. One lamp was provided for each of the systems on each of the rear fenders and a headlight and two turn signals were mounted on the front. (See Figures 19 and 20.)

The brake lights consisted of two red 12 volt lamps wired in parallel and across the normally closed position of the brake safety microswitch; so that when the switch was held closed (brakes not applied) the circuit was open, but when the brakes were applied the switch was unloaded and the brake light circuit was energized.

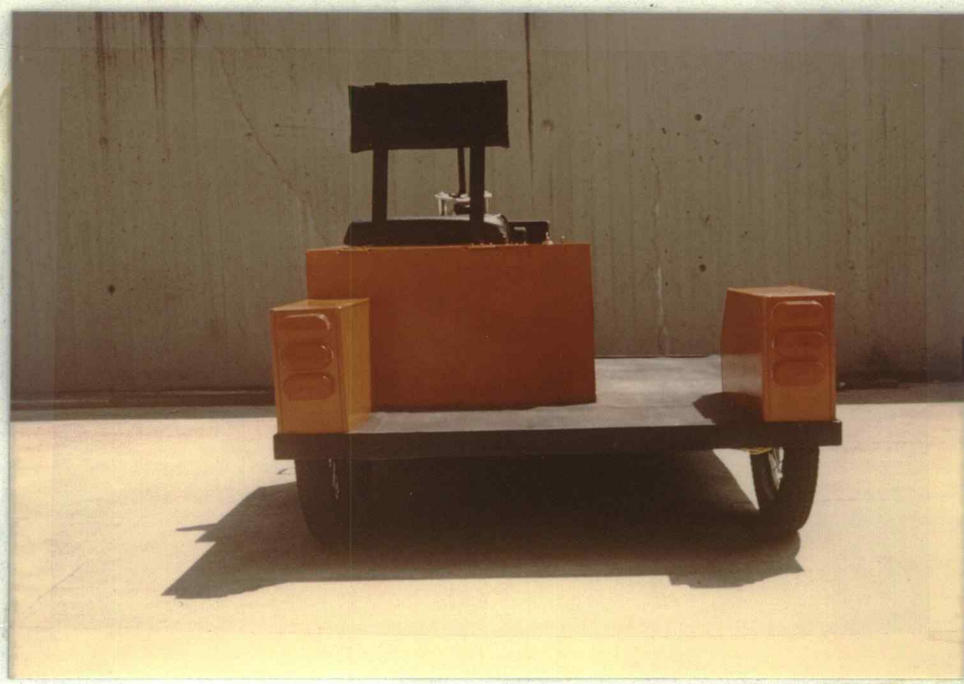

Figure 19. Back View MOD 2

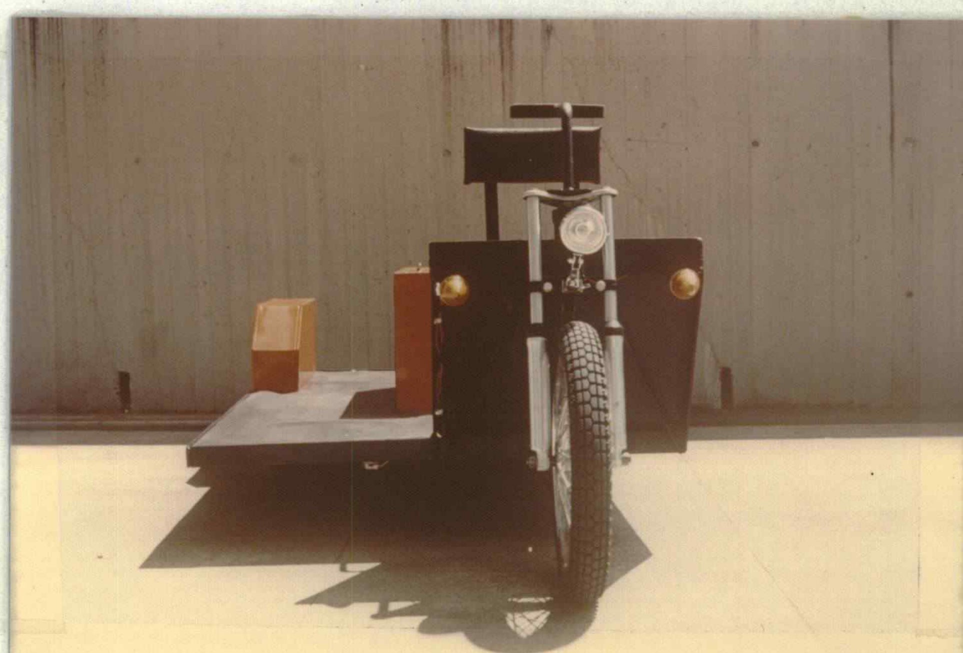

Figure 20. Front View MOD 2

The running lights were two red 12 volt lamps in the rear and the headlight in the front, all being wired in parallel. These lights by-passed the keyswitch and seat safety switches so that they could be used with no operator present. The headlight was an adapted battery powered bicycle headlight converted to operate on 12 volts, and drawing its power from the control circuit. This convertion implied removing all battery connected controls and replacing the standard three volt bulb with a 14.4 volt bulb. The headlight was mounted on the front fork directly above the front wheel so it swivelled with the wheel and always illuminated the path directly in front of the vehicle.

The turn signals consisted of two red 12 volt lamps at the rear and two amber lights in the front, mounted on the front fork support assembly. Each bulb was wired in parallel and the main positive lead was wired through a standard automotive flasher. The signals were controlled by a three position toggle switch, with the responsibility of turning the lights on and off resting with the operator. The flasher was mounted on the solenoid mounting plate. (See Figure 17.)

The five solenoids were mounted on a 10 x 14 inch steel panel mounted to the inside of the front seat frame side panel. Battery cables ran from the solenoids to the motor, mounted directly aft, to the negative terminals of the battery packs and to the manual disconnect switch (positive battery pack leads). Control wires (16 gauge) ran from the solenoid activation lugs to the manual disconnect switch, the switches on the control panel, and to the lights and horn. The manual disconnect switch was mounted on the seat frame directly under and inside the top of the left side. The batteries were set in an "L" shaped galvanized steel battery box in the right half of the seat frame assembly. The control panel was directly to the right side of the operator's seat, with a total of six switches mounted on it (key, horn, on-off, forward-reverse, lights, and turn signals). These switches were in three rows of two.

The seat activated safety switch was bolted to a piece of angle iron directly below the operator's seat so that it was in contact with the seat base plate.

The foot speed control microswitches were mounted on the foot feed mounting plate, which was bolted to the floor plate. They were covered with a protective sheet metal box. The brake microswitch was bolted directly to the underside of the floor plate ahead and to the right side of the brake cable tension equalizing yoke.

The horn was mounted on a strip of insulating plastic on the lower side of the frame, since the frame of the vehicle was not grounded. The lights were mounted on the backs of the fenders (brake, running and turn signals), on the front fork support (turn signals) and on the front fork above the front wheel (headlight). (See Figures 14, 19, and 20.)

All wires to the lights, horn, and switches were bundled if possible and attached to the underside of the frame.

Pedals and Linkages

Brakes. The same braking system was used in the MOD 2 as developed for the MOD 1 except for changes necessary to fit the vehicle geometry. The left brake was activated by the standard motorcycle brake cable but the right cable was a motorcycle clutch cable (Honda GL-1000) adapted to fit onto the brake arm at the wheel. A small steel tab was mounted on the brake activation rod to trip the brake safety microswitch. (See Figure 11.) The brake cable sheaths were held at the wheels by brackets bolted to the frame members on the outer edge of the wheel wells. The brake anchor arms were bolted directly to these same members. Both of the actual brake arms (on the wheels) were swivelled 180 degrees from their original positions so that they would not stick out past the edge of the vehicle frame. The right wheel had only one bolt through the outer frame for both the anchor point and to hold the cable bracket, due to the asymmetric mounting the left wheel required two bolts.

The parking brake was an "L" shaped assembly hinged to pivot directly behind the brake pedal when it was in an off position. When in use the parking brake would be swung forward and caught under a small screw set in the main brake pedal so that the main brake lever was held forward in an applied position. (See Figure 21.) This kept the brakes fully applied and turned off the brake safety microswitch.

Speed Control. The speed control system consisted of two microswitches designed to activate one after the other due to the action of a foot lever on one or both of two secondary levers. Pressure on the foot lever caused a flange on the bottom of the lever to come into contact with the first secondary lever, which activated the first microswitch. Continued pressure would cause a second flange, recessed with respect to the first, to contact the other secondary lever, which in turn activated the second microswitch. Return springs of differing spring constants on the secondary levers provided the operator with a feedback response of the switch position. This system was mounted in a

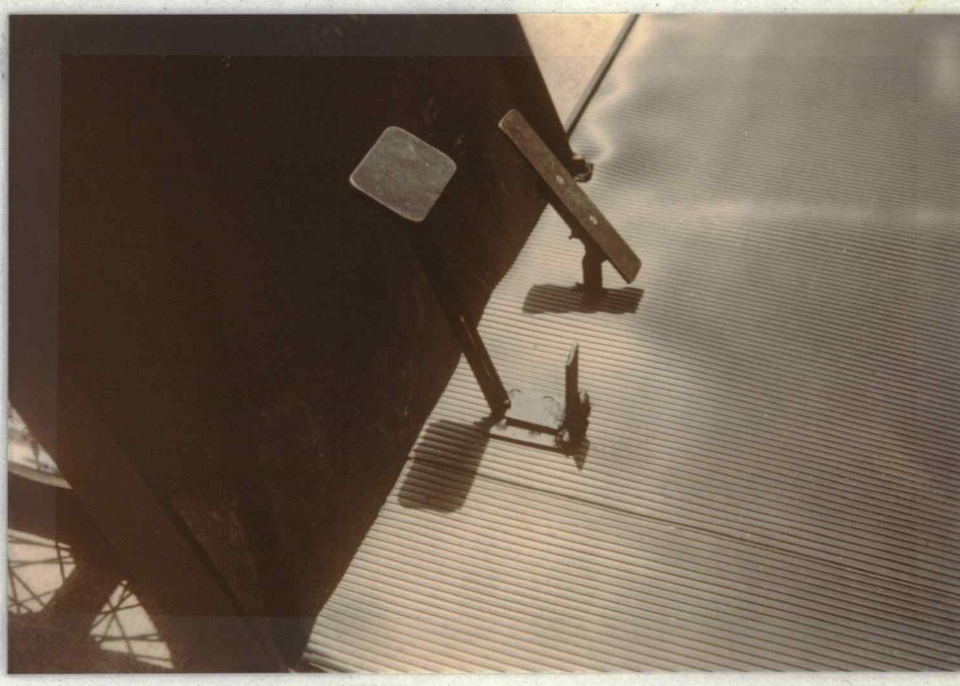

Figure 21. Pedals: Parking Brake Set MOD 2

section of fabricated C channel and covered with a removable waterproof metal box. This assembly was bolted to the floor plate on the right side of the brake pedal just behind the front fork support.

Testing Procedure

The same tests were run on the MOD 2 as were developed and run on the MOD 1 so that the vehicles relative performance could be determined.

Results-Electric. The no load tests on the MOD 2 showed that the steady state current draw in low speed was 15 amps and that in high was 16 amps. The no load transients from speed changes were: off to low, 33 amps, low to high, 28 amps, and off to high, 42 amps.

Service type tests with operator only on the Benton Hall Circuit showed that the maximum steady current draw while climbing the hill on the route was 44 amps and the lowest reading, while the vehicle was going downhill, was 20 amps. (See sample chart in Appendix.) Initial starting transients under load were about 85 to 90 amps when the motor was cold and about 66 amps after it had been running for several minutes. The highest observed transients occurred when starting on a hill from a dead stop, this being 108 amps. All transients damped out after about 4 seconds.

On long runs on level ground the MOD 2 reached a steady state current draw of 24 amps. For each additional load increment of 100 pounds carried while climbing the hill on the Benton Hall Circuit the current draw increased about 2.5 amps from an apparent lower limit of 44 amps.

Driving endurance tests showed that, although the MOD 2 had an endurance of approximately eight hours on level ground, it became almost totally unable to climb any hills after about five hours of constant use.

Results-Driveability. Fifth wheel tests on the MOD 2 showed the top speed on level ground to be 10.5 mph with one operator and no additional load. In a sustained hill climb this speed would decrease to a minimum of about 3.5 mph (on the sidewalk directly north of Mitchell Playhouse, the steepest hill on the Oregon State campus). The speed in low was about 5 mph and the speeds in reverse were the same as the speeds forward. As in the MOD 1, a one to one and a half mile per hour speed reduction was observed with each additional load increment of about 150 pounds. Time to top speed on level ground was 3-4 seconds, with a longer time being necessary on hills.

Steering response was very smooth and much more stable than the MOD 1, but was not as quick and responsive. The MOD 2 could easily be driven "hands off" for long periods of time (greater than one minute) without diverging from a straight line course.

The MOD 2 did not have any of the problems of the MOD 1 associated with starting on loose surfaces and the surface rolling resistance did not effect its steering response to any noticeable extent.

The vehicle was very easy and safe to control in both reverse speeds, with no instability problems when in high speed reverse.

In a fully locked left turn the vehicle would turn about a 10 foot diameter circle and the right, a four foot diameter circle; so it was possible to turn the MOD 2 around within about a 12 foot wide space. The physical steering limits were such that the front wheel always rolled smoothly in any corner and the vehicle could go into a fully locked turn at high speed in either direction with no tipping or skidding problems. Due to the relatively low speed there were no appreciable G forces on the driver in this condition.

The MOD 2 brake system worked well when the vehicle was moving forward, but one of the consequences of using motorcycle brakes was that they were not self-actuizing in reverse, so that the stopping distance in reverse was about half again as much as going forward. This also caused the brakes to slip if the vehicle was parked on a hill if it was pointed towards the top. If the vehicle was pointed down the hill the brakes would self-actuize and the main brake and parking brake would both hold the vehicle solidly in place.

The MOD 2 had most of the terrain capabilities of the MOD 1. It did not have any tendency to veer to the side on a loose surface, but since it was a lower vehicle it could only go up a five to six inch curb and would bottom out on any obstacle five inches high and any less than two feet long. The bottoming out point was the bottom of the brake assembly.

Operators that had driven both vehicles felt that the MOD 2 was rather sluggish and not as responsive as the first vehicle, but they did think that it was a smoother riding and driving vehicle and did not have any of the MOD 1's stability problems.

First time MOD 2 operators tended to overemphasize the width of the vehicle and focus too much attention to the right front corner; consequently they would uniformly swing too wide in any turn to the right. In actuality the MOD 2 was four inches thinner than the MOD 1 (44 inches and 48 inches, respectively) but operators usually drove it as if it were wider due to the very visible front corner. A collision in the MOD 2 could be of more serious consequences than in the MOD 1 because the front corner provided a much greater chance of snagging an obstacle instead of glancing off it.

One of the advantages of the asymmetric seat mounting was that the operator had a better view of the vehicle path while backing up, making the risk of a collision in reverse much less than in the MOD 1.

The control system of the MOD 2 was more complicated than that in the MOD 1 but potential operators did not seem to have too much more trouble adapting to it. For all its added switches it remained a very easy vehicle to drive.

Design Discussion

The MOD 2 vehicle moved to an easier to fabricate frame configuration. Frame assembly was done on a simple jig constructed from a piece of plywood; bar stock members were simply cut (all right angles), dropped into place, and welded. The diagonal bracing members were added after the basic frame had been constructed. The metal floor plate made the vehicle more durable and, since it was set below the level of the outer frame members, a lip was provided along the outside edges to prevent loads from sliding off during operation. The rear fenders and sides to the seat frame prevented cargo or passengers from becoming entangled in a wheel, the drive system or any of the many electrical wires.

The rear axles were mounted directly through the frame so that they could better transfer the load throughout the side members. Also, no additional assembly was required and the vehicle was lower to the ground.

The seat frame side panels and the fenders would slow up major repair to the drive or electrical systems but the front, rear, and left side panels and both fenders were removable and the entire seat frame could be unbolted and lifted off the floor plate if desired. This would be necessary to remove the entire battery box from the vehicle; but since the seat base plate, the control panel and their supporting members could be unbolted and removed almost any adjustment could be made from the top--including replacing any or all of the batteries.

Some concern had been expressed about relative range reduction due to the extra two solenoids and the necessity of activating them for operation in reverse, however, the actual time driving in reverse seldom would amount to any significant percentage of the total driving time. Also the electrical tests showed that the gear belt drive system had a lower current draw in steady state conditions than the chain drive of the MOD 1 and was, apparently, a more energy efficient drive system. (The increase in peak current under load seems to be due to the increase in overall vehicle weight.)

Economic considerations. Total material cost for the MOD 2 was about $1000; this was higher than would be necessary for a production run because it was a one of a kind vehicle and all subassemblies were purchased commercially at costs greater than could be expected if buying in lots. It is estimated that a production run of 10 would cost $600-$700 per vehicle (with all new parts). In operation the vehicle recharging costs could be at most 12 cents per day (4.5 kw-hr, based on recharging each battery 2.5 hours at 20 amps); so that day to day cost of operation would be quite low, but the batteries would have to be replaced every few years at a cost of about $40 apiece. Whether the vehicle would compare favorably to a petroleum powered vehicle would depend on the geographic location, the intended use, and the personal feelings of the potential operators.

Further Vehicle Redesign

Any time an article is actually put into service, problems tend to appear that the designer had never considered or had entirely overlooked due to his understanding of the design idiosyncrasies; and this is sure to happen in this case. Due to the simple fabrication techniques and easily acquired materials it would be a relatively simple matter to adapt the design to fix most, as of yet undiscovered, design deficiencies.

The possible in-use modifications to the vehicle would be to custom fit it to its specific intended job duty, such as: adding a cargo box to carry mail, clamp down lugs to carry a tool chest, ties or cradles to hold ladders or pipe, and especially, the design of a rainproof canopy over the operator. Aside from major modifications, service life may show that some vehicle components are not durable or reliable enough, and they will have to be changed. This process will continue as long as the vehicle is in service.

Some specific further work areas might be to: round off the right front corner to reduce the risk of an accident, put in a gear belt drive between the motor and the jack shaft for uniformity, develop a cheap SCR (Silicon Controlled Rectifier) speed control system for smooth speed changes, change the wiring so that all the lighting system control switches were in the tiller bar handle, and find a different plate material that would make for a lighter vehicle.

IV. CONCLUSION

The original design goals called for the vehicle to be planned such that a small number could be constructed and put to use as service vehicles in some installation. Vehicle performance has shown this to be entirely feasible. The second vehicle, the MOD 2, is a safe, inexpensive, easy to handle and durable vehicle that could be built simply by trained personnel. It meets or exceeds all design requirements.

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APPENDIX

The original sizing of the frame members was done by a yield stress analysis of the side members, where the assumed loads acted on the side member at positions relative to their center of gravity on the entire vehicle. The beam was assumed to be non-buckling. The assumed loads included the operator, frame weight, four batteries, motor, miscellaneous extra weight and a second person or load directly on the side frame member just forward of the seat framework. The point of maximum bending moment was determined and the stress at the outer fiber at this point was set equal to the yield stress for the material (mild steel). This left the moment of inertia as the only unknown and allowed the thickness and height of the beam to be adjusted according to the resulting formula:

$$t = 0.582/h^2,$$

where t is the beam thickness in inches and h is the beam height in inches. This equation showed that a piece of mild steel bar stock 0.25 x 2 inches would be adequate (factor of safety about 1.75).

Later a more rigorous and accurate analysis was carried out using SAP IV, a stress analysis program developed for the National Science Foundation by the Earthquake Engineering Research Center, Berkeley, California. In this analysis beam elements were used for the frame members and plate elements (capable of taking bending stresses) were used to model the floor plate. Loads were applied at the nodes in a representation of the vehicle, operator, and a 210 pound load on the rear cargo deck.

The analysis showed that the maximum nodal point deflections occur along the middle longitudinal frame member and are of the order of 0.13 inch. The stresses in the members were shown to be quite low, with the maximum axial stress being just under 1200 psi and the largest shear stress being about 425 psi in the beams and the maximum plate stresses being 87 psi. All members were shown to be well below their yield points.

The pertinent data from the program follows.

The forces input to the program correspond to a lumped approach to splitting up the masses of the various vehicle components and applying them at the nodal points. The boundary conditions constrain the displacements of the nodal points corresponding to the axle points (8, 9, 10, 11, and 29; See Figure A-1). The forces are as follows, where the Z axis corresponds to the vertical direction on the frame:

N O D A L L O A D S (S T A T I C)

NODE NUMBER	LOAD CASE	X-AXIS FORCE	Y-AXIS FORCE	Z-AXIS FORCE
15	1	-0.	-0.	-.18000E+03
16	1	-0.	-0.	-.40000E+02
17	1	-0.	-0.	-.40000E+02
19	1	-0.	-0.	-.18000E+03
20	1	-0.	-0.	-.40000E+02
21	1	-0.	-0.	-.20000E+02
23	1	-0.	-0.	-.20000E+02
24	1	-0.	-0.	-.20000E+02
31	1	-0.	-0.	-.70000E+02
32	1	-0.	-0.	-.70000E+02
33	1	-0.	-0.	-.70000E+02
35	1	-0.	-0.	-.40000E+02

TABLE A-1. INPUT NODE POINT FORCES

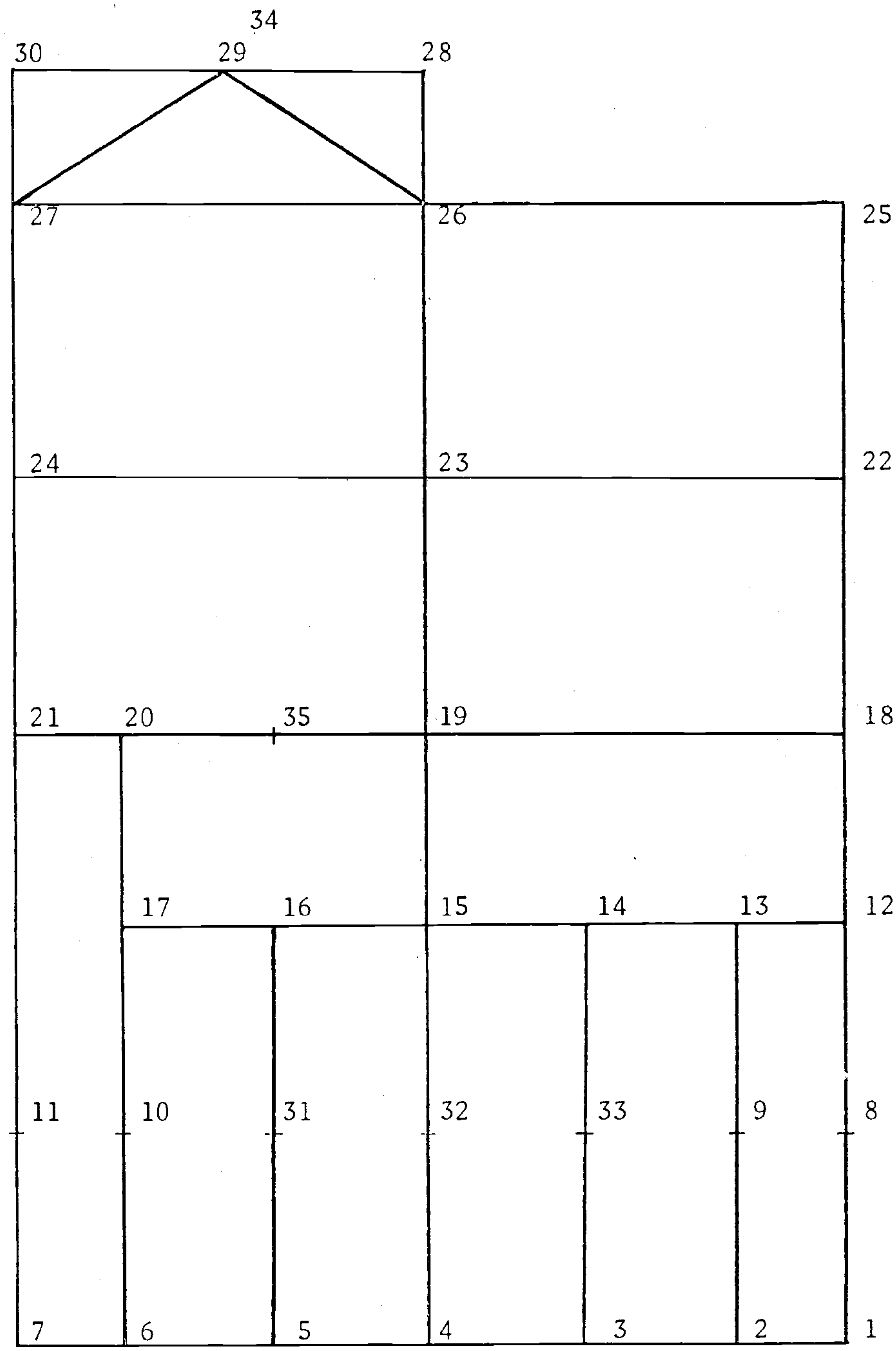

Figure A-1. Node Points MOD 2

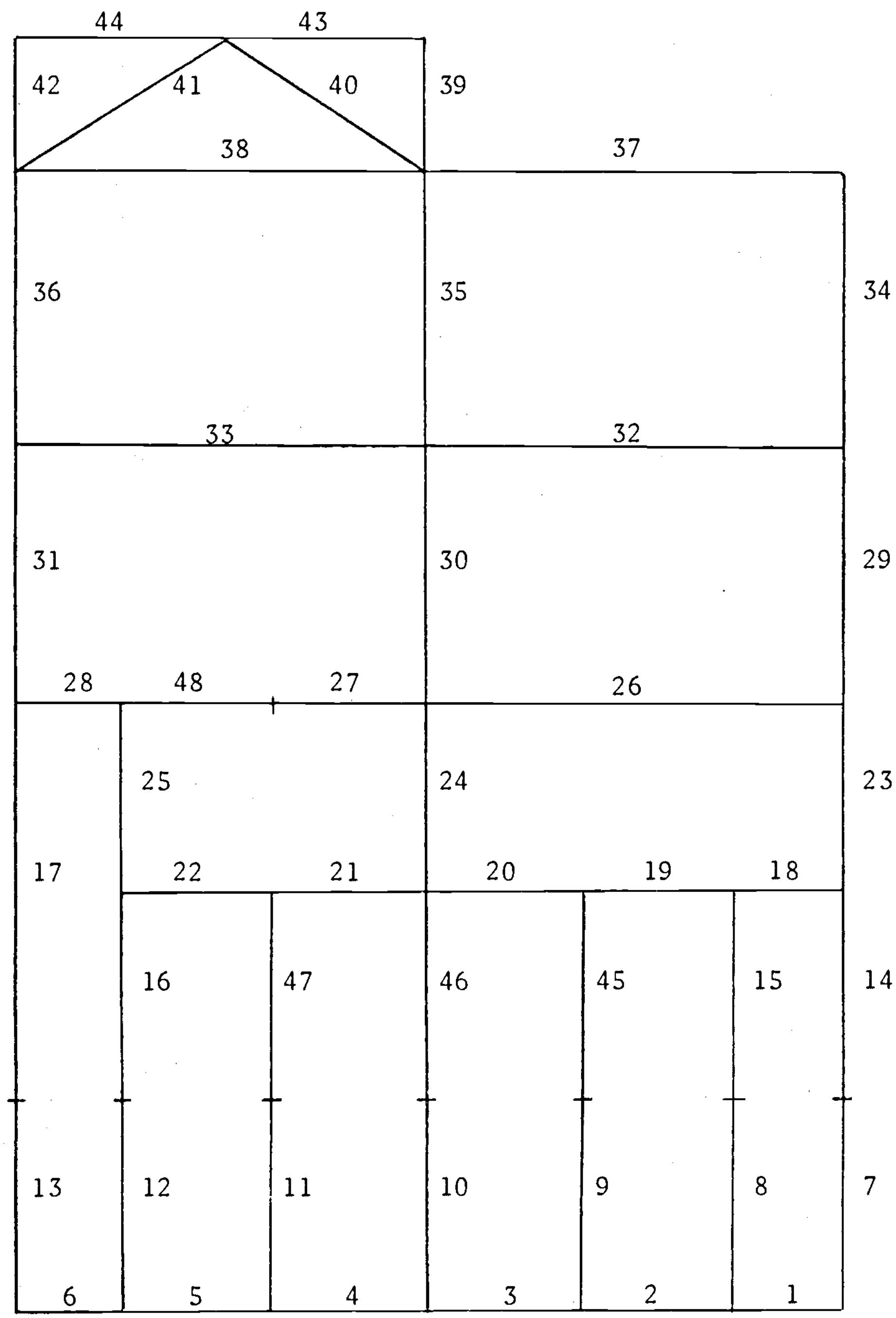

Figure A-2. Beam Elements MOD 2

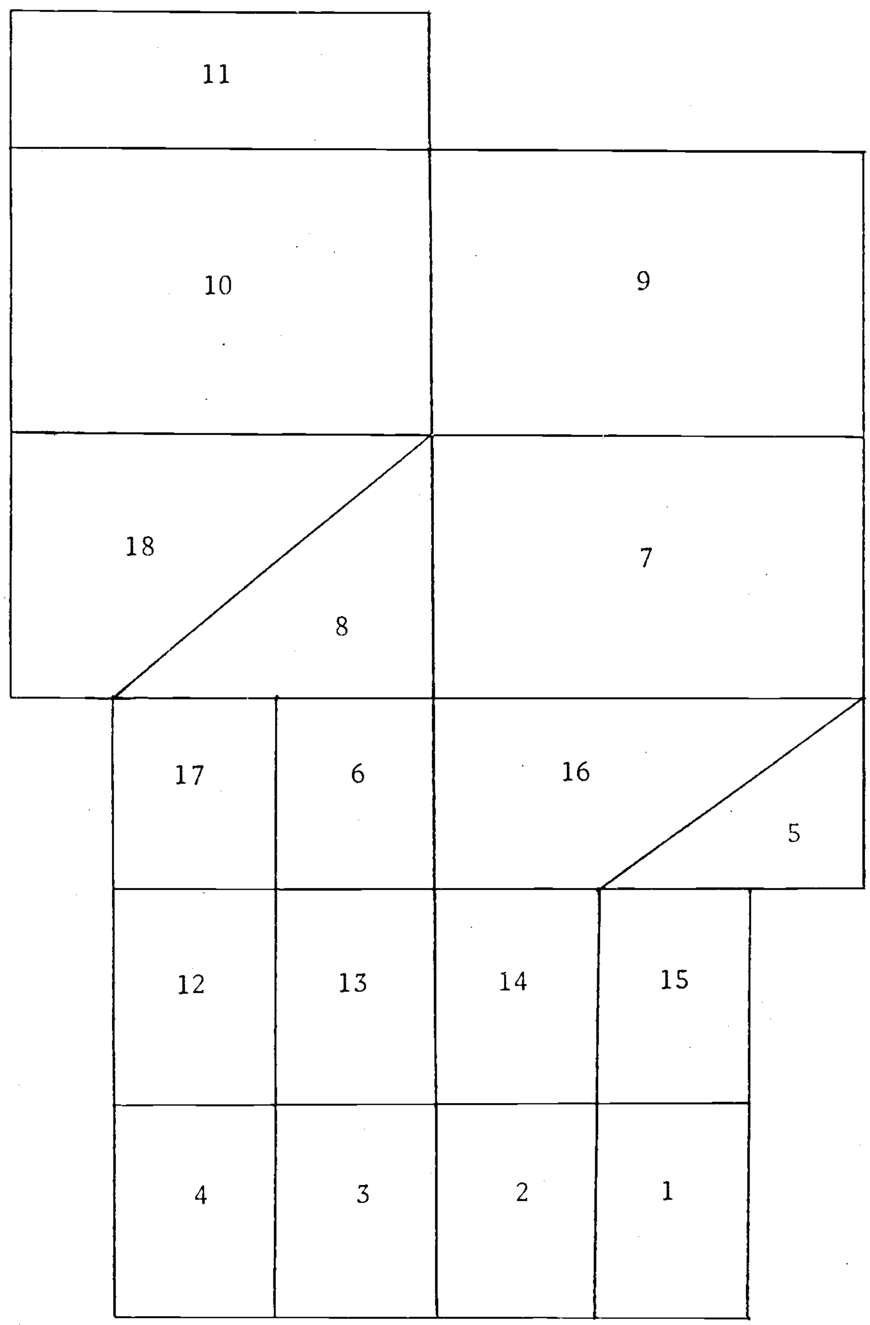

Figure A-3. Plate Elements MOD 2

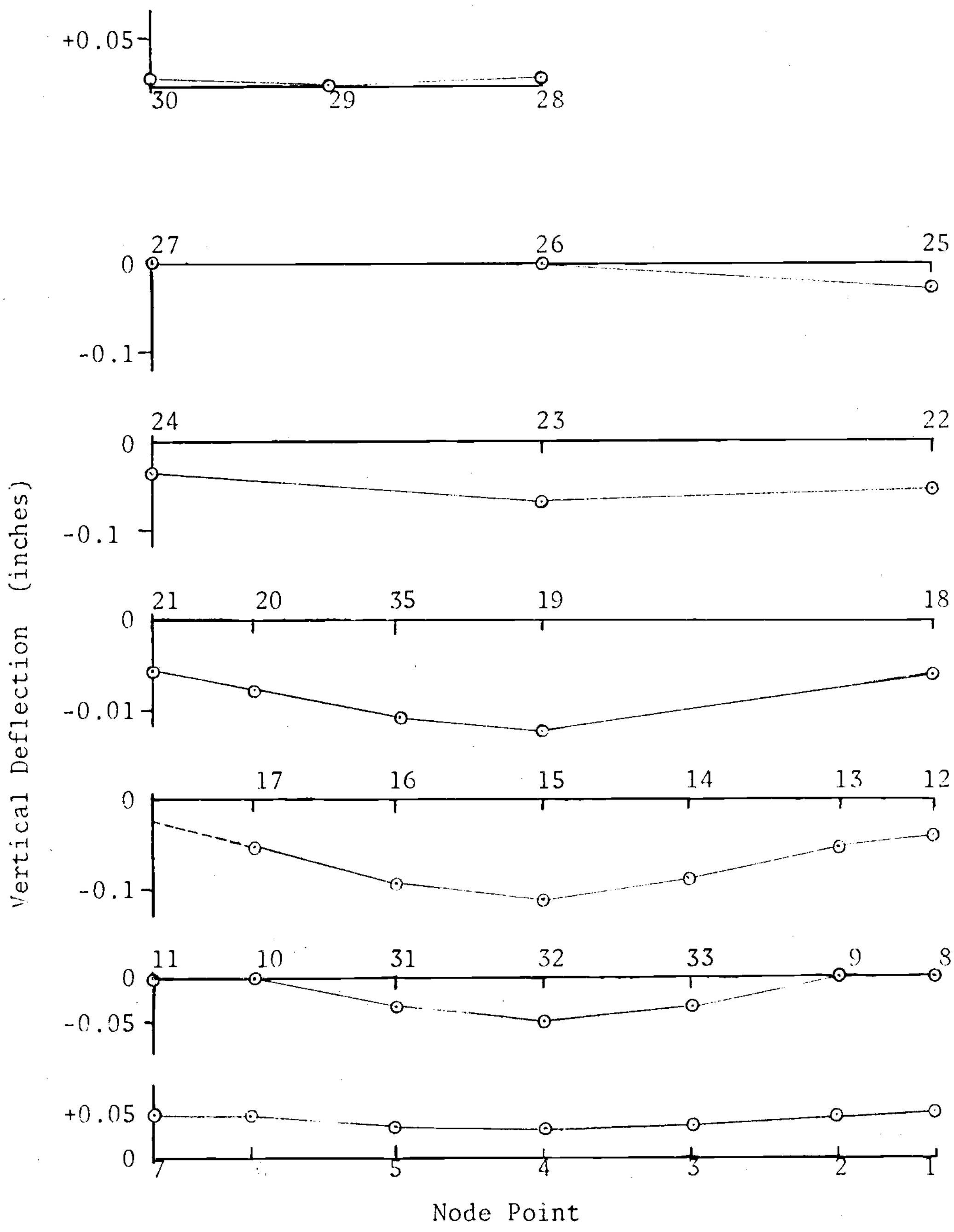

Figure A-4. Nodal Point vs. Deflection (Lateral Frame Members, not to scale)

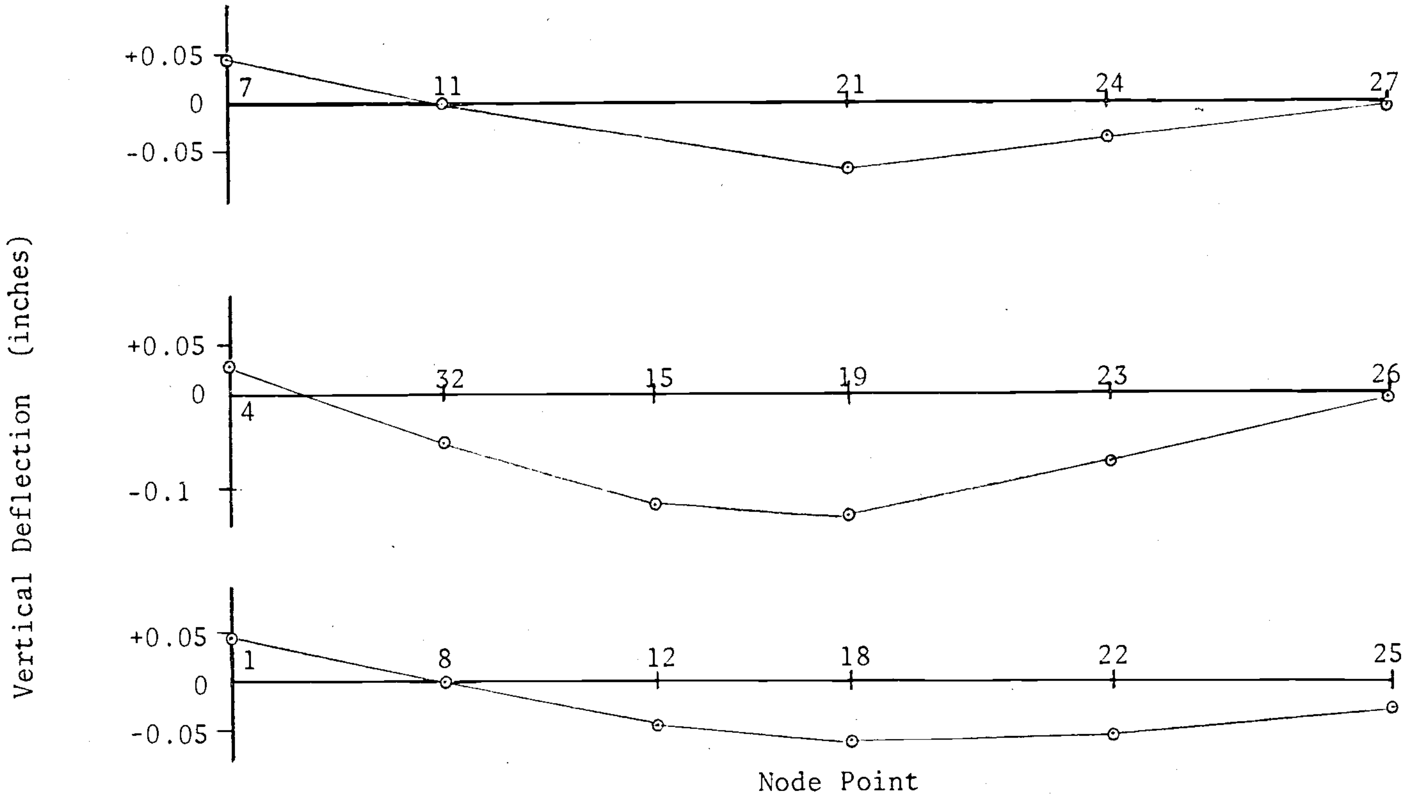

Figure A-5. Nodal Point vs. Deflection (Longitudinal Frame Members, Not to scale)

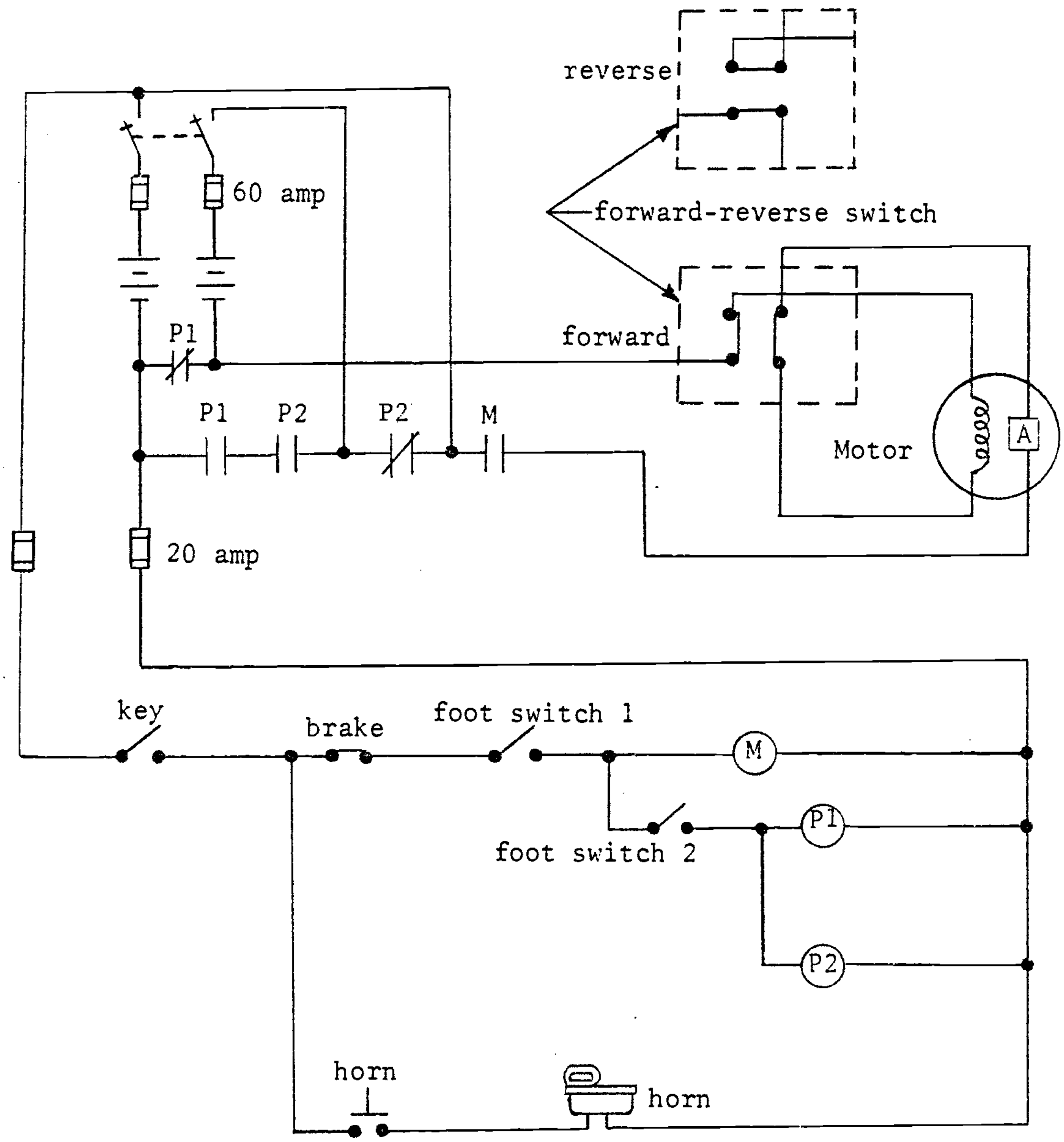

Figure A-6. Electrical System MOD 1

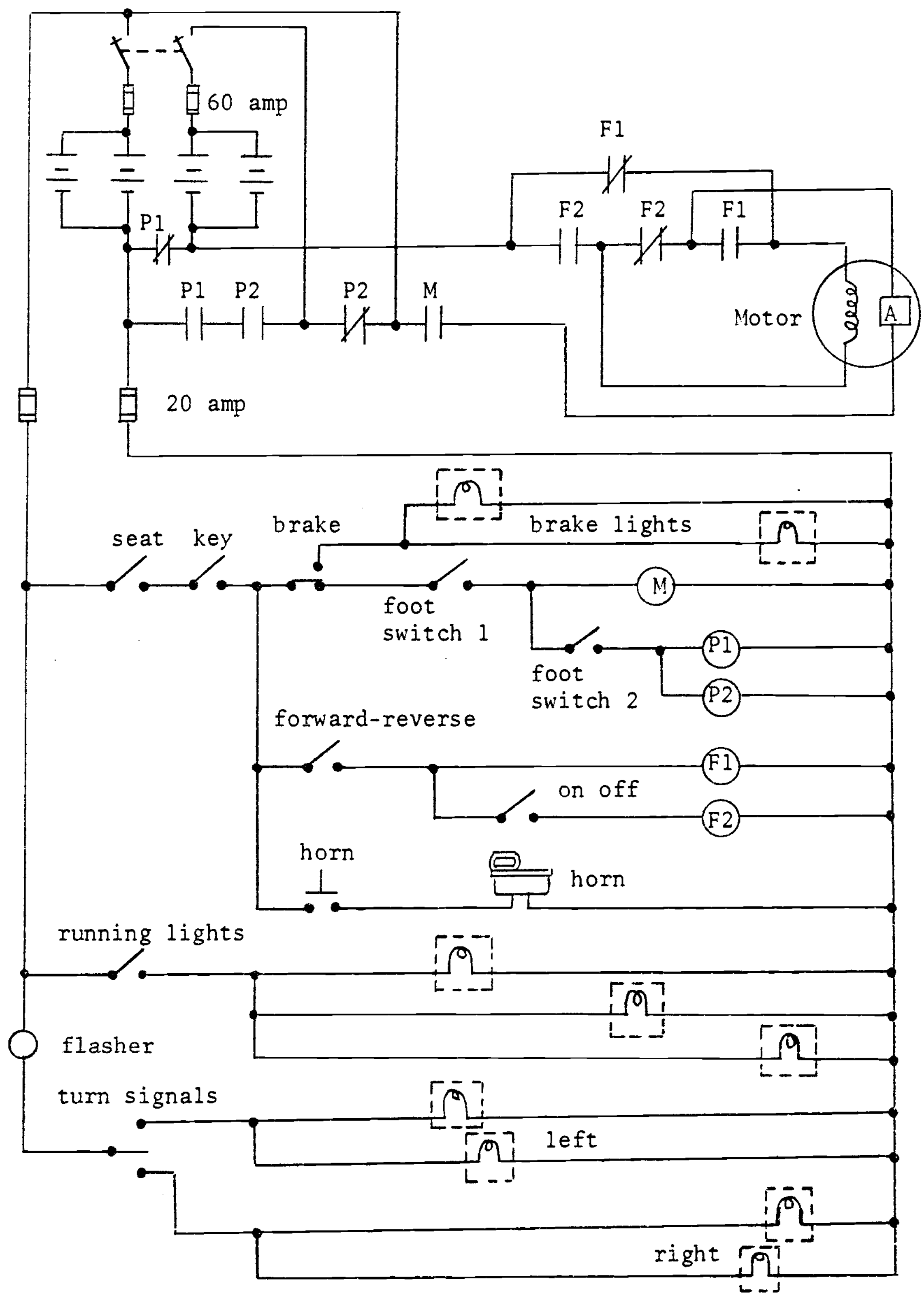

Figure A-7. Electrical System MOD 2

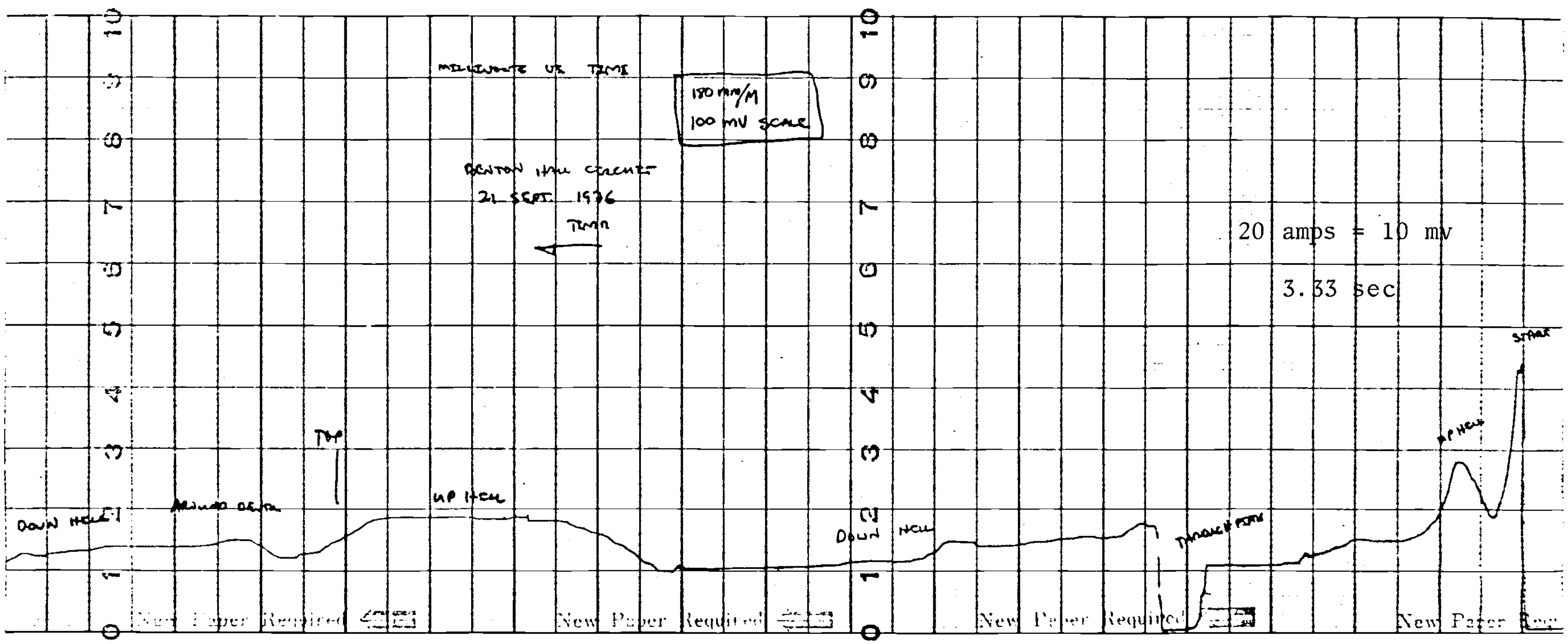

Figure A-8. Partial Benton Hall Circuit MOD 1

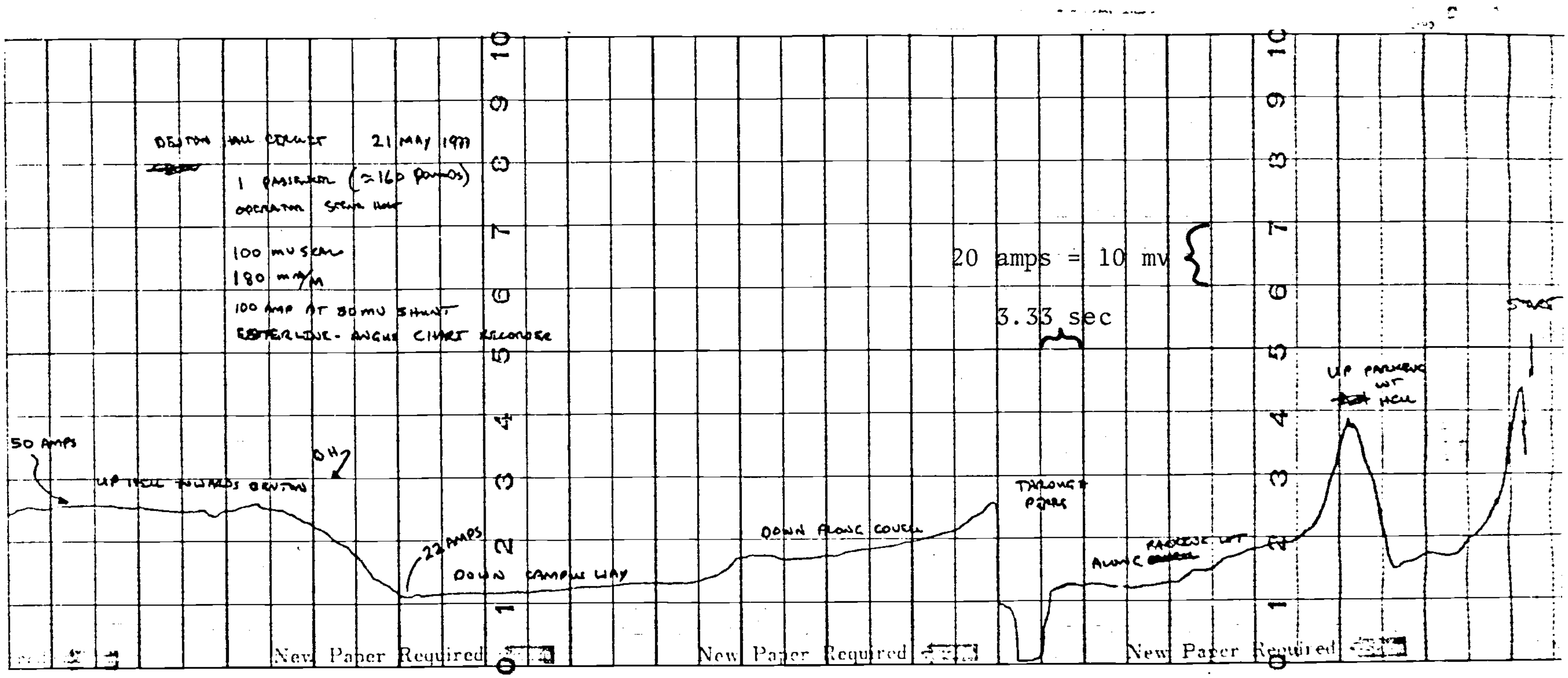

Figure A-9. Partial Benton Hall Circuit MOD 2