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# SURVEY OF SLIDING CONTACT/SOLID RAIL POWER COLLECTION SYSTEMS FOR APPLICATION TO THE TRACKED AIR CUSHION VEHICLE

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16. Abstract

The objective of a power collection system is to deliver uninterrupted power from the wayside to a vehicle. In order to apply the third rail concept, used for subway power collection, to the tracked air cushion vehicle, considerable improvement must be made in the design to accomodate higher speed, higher power, and larger lateral motions. This report classifies sliding contact collectors for solid rails, discusses merits and problems with each, and surveys several existing and planned sliding contact collectors.

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# INTRODUCTION

With increased speed and power demands on electrified mass transportation systems, there has been a need to examine power collection techniques in order to ascertain which will most economically meet performance requirements while providing the required safety to passengers. The objective of a power collection system is to deliver uninterrupted power from the wayside to a vehicle. There are two basic categories of collection systems: noncontact systems and contact systems.

Noncontact systems, such as induction coupling, capacitive coupling, and electromagnetic wave guide coupling, are not feasible at the present time because of low efficiencies and the requirement for high frequency power distribution which is very expensive. A controlled electric arc presents problems with arc extinguishing, material wear, and radio noise which cannot be overcome with present technology.

Contact systems include pantograph/catenary systems, and solid rails with wheels, or brushes. Pantograph/catenary systems operate at 150 mph on the Metroliner and have achieved a speed of 200 mph for a short period of time on a French National Railway train prior to burning up the pantograph. Because the critical operating velocity resulting from wave motion in the catenary is low (250 mph on the Japanese Tokaido line which has trains operating at 125 mph) there seems to be an upper limit on speed using such a system.

Use of wheels rolling on solid rails does not appear to be practical since it involves small contact areas and high current densities; power must be collected twice, and it is hard to maintain wheel to rail contact.

Sliding contact collectors on solid rails, despite their "non-sophistication", seem to offer the most practical method for collecting power from the wayside for the next decade.

The following section classifies the various types of sliding contact collectors for solid rails and discusses, in general, merits and problems with each. The remainder of the report discusses several existing and planned sliding contact collectors and the problems they have encountered.

# SLIDING CONTACT COLLECTOR CLASSIFICATION

Sliding contact collectors for solid rails can be categorized by the way they maintain brush to rail contact:

1. Paddle Type - the brush is held to the rail by passive elements (springs, and dampers) or active elements (e.g., hydraulic actuators) which react against the vehicle.
2. Captive Type - the brushes and collector body are attached to the rails such that they cannot escape from the 3 rail cross section and need only be attached to the vehicle with a tow arm for pulling the collector down the track.

## PADDLE TYPE COLLECTOR

Paddle collectors with passive elements are used on most transit systems now operating in the United States. Figure 1 is a typical configuration for such a collector. The BART system and Transit Expressway system, state-of-the-art transit systems, described in this report, have selected collectors of this type. All of these applications have been at speeds less than 80 mph.

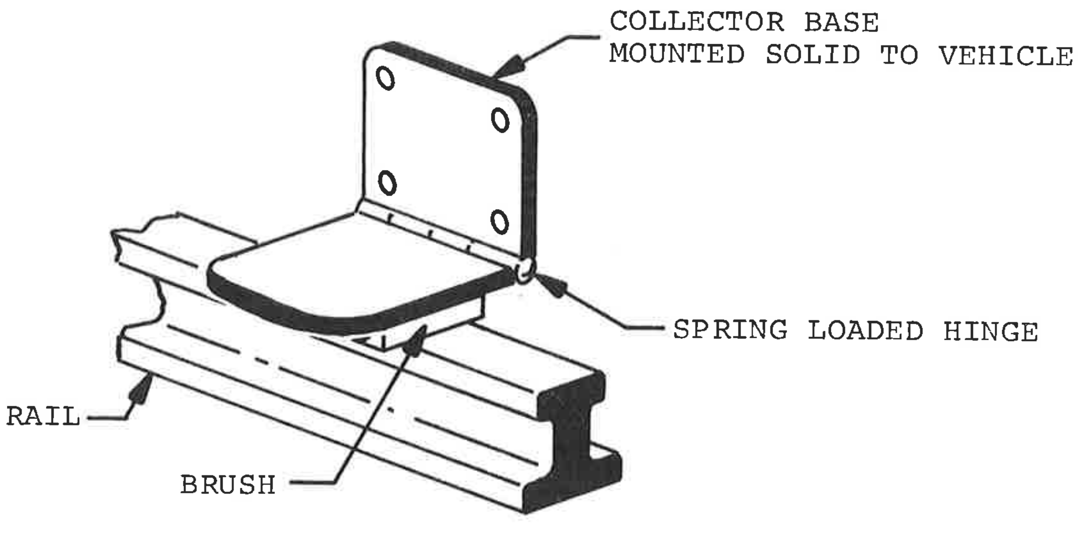


Figure 1. Typical Paddle Type Collector

The design objective is to tune the simple spring mass system so that the preload will remain constant under the predominate forced oscillation. This produces the least mechanical wear. Adjustment of the preload is made to minimize electrical wear due to arcing at runoffs.

Recent studies suggest higher speeds can be achieved. (Reference 1). However, because the design parameters available for improving performance are limited (preload and natural frequency) and because transverse vehicle to rail motion of a TACV is large, it is difficult to obtain satisfactory performance over a wide range of operating speed. The alternatives are to replace the passive elements with active elements or use a captive collector.

Active elements such as hydraulic or pneumatic actuators have the capability of quick response to large vehicle to rail motions. Figure 2 is an active system as it might be implemented. There are no known active collector systems in operation at this time.

If constant brush to rail force, F, is desired under accelerations due to rail irregularities and vehicle motion, the actuator must supply a force P, given by

$$P = -m \frac{d^2 x_V}{dt^2} + F \qquad (1)$$

where m = collector mass

$\frac{d^2 x_V}{dt^2}$ = vehicle acceleration relative to rail

It is not possible to implement this control law precisely because of time delays in the feedback loops, and mechanical impedance in the actuator. Thus, one can only hope to limit the fluctuation in F and perhaps rely on additional passive elements for improved performance.

Choice of sensor is probably dependent on the specific application. A pressure transducer which measures drop across the hydraulic actuator is the simplest sensor available, and appears to be the preferred way for regulating P.

Direct measurement of $\frac{d^2 x_V}{dt^2}$ requires two accelerometers,

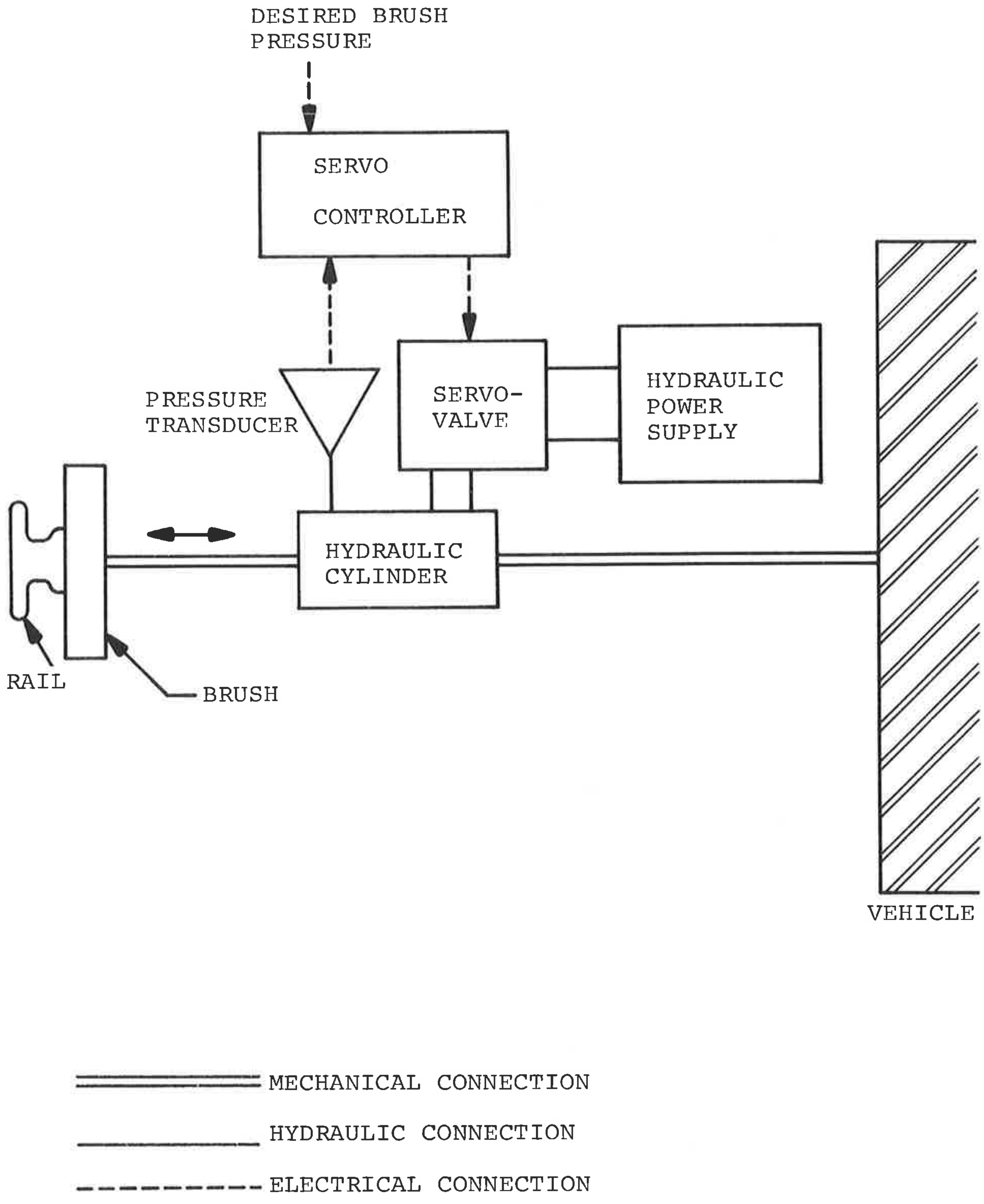


Figure 2. Typical Active Collector

one mounted on the vehicle and one mounted to the brush or brush holder (assuming the brush follows the rail). An inherent error still exists because the accelerometers measure inertial acceleration and could be picking up vehicle acceleration as it rounds curves. However, this error is small, and of such a frequency that it could easily be compensated. Other sensors which measure displacement and/or velocity of the vehicle relative to the rail such as electromagnetic transducers, capacitors, radar, etc. can be processed to give the desired acceleration data. This technique is attractive because displacement and/or velocity signals can be used to stabilize the control loop.

## CAPTIVE TYPE COLLECTORS

A captive type collector was demonstrated on the French Aerotrain in 1969 (See section Aerotrain Demonstration Vehicle.) British and United States TACRV demonstration projects will also use captive collectors, indicating that the concept looks attractive for high speeds. Figures 3a & 3b depict how captive systems might be held within a 3 rail configuration and how individual collectors might be held to a single rail,respectively. Other captive configurations using wheels or pairs of wheels to hold the collector to the rails have also been suggested.

In addition to the simplicity of a captive system, it can provide increased assurance of continuous rail contact by using opposite facing brushes on each rail such that one is in contact if the other has separated due to inertia forces. Rail-brush interaction is also reduced since brush preloads cancel so as not to bend the rail. At least two sliding surfaces are required on the rail, making rail manufacture and installation tolerances more critical. A tradeoff study could determine whether the additional cost of a captive system with opposite facing brushes on each rail is warranted.

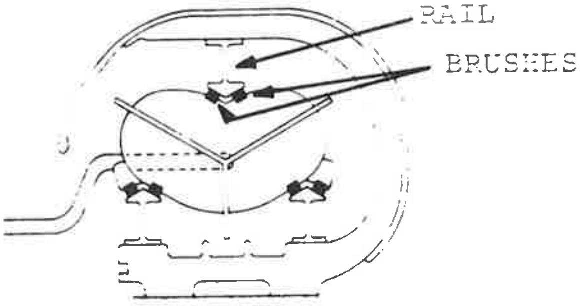


Figure 3a. Collector, 3 Rail Captive

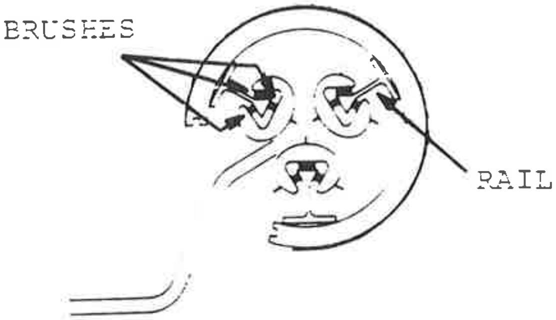


Figure 3b. Collector, Single Rail Captive

# SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT (SFBARTD) DEMONSTRATION PROJECT (REFERENCE 2)

The BARTD Demonstration Project was conducted on a pair of four and one half mile test tracks between Concord and Walnut Creek, California. The purpose of the project was to test and evaluate new technical concepts in the field of rapid transit.

Sliding contact power collection was demonstrated for 1,000 volt direct current and 3-phase 4160 volt alternating current, both on a wheeled vehicle with a maximum speed of 80 mph. Two dc and four ac collectors were evaluated along with several rail configurations and compositions.

## A.C. POWER COLLECTION

Tables 1 and 2 are the design criteria for contact rails and Table 3 is the design criteria for the collector, as prepared by Parsons Brinckerhoff-Tudor-Bechtel, consultants to the BARTD. From these, various contact rails and power collectors were developed under contract for demonstration.

Initially a contract was awarded to the H. K. Porter Company for the development of a collector test facility, prototype collectors, and the prototype contact rail.

The current collector test facility was designed to simulate as closely as possible the conditions that might be encountered in the operation of a rapid transit system. The facility consisted primarily of a horizontally mounted wheel, 12 feet 9 inches in diameter, with six conductors or rails mounted with six-inch phase spacing in the vertical plane. The wheel was capable of being rotated in both the forward and reverse directions with peripheral speeds up to 80 miles per hour. The rotating wheel simulated the motion of a train moving parallel with the contact rail at any desired speed. The motions of the car trucks were simulated by mounting the current collector on a stand which could move the collector vertically or horizontally, pivot it vertically and horizontally, and allow the entire assembly to be moved away from, or onto, the rail in a direction perpendicular to the collection face of the rail. This last motion was to simulate the run-on/off characteristics of a collector at gap-end approaches.

The test wheel and collector stand were connected electrically so that the collector could be operated at three-phase 4160 volts and under loads varying from 20 to 600 amperes.

## TABLE 1. PRELIMINARY CRITERIA FOR THREE-PHASE THIRD RAIL

Voltages: 600, 2400, 4160

Conductors: 3 (Alternatively 2, if running rail used as third conductor)

**Train Power Requirements:**

Kw per car: Approximately 200 at balance speed, four to five times above during acceleration periods of ten to 30 seconds

Cars per train: 10

**Conductor Arrangements:**

Vertical with side contact collectors

Horizontal with under-running collectors

Triangular with internal or external running collectors

Conductors may be completely bare, mounted on porcelain insulators and spaced for air insulation, or may be continuously insulated (except for collector surface), closely spaced, and provided with barriers to prevent flashovers started by collector sparking.

**Safety Requirements:**

Right-of-way will be subway, elevated, or completely fenced where at grade.

Protection against accidental contact by maintenance personnel or track-walkers falling against conductor system is required.

**Space Limitation:**

Third-rail system must be limited to not more than two feet six inches above top of rail to fit under platforms at stations.

**Information Required for Three-Phase Third Rail:**

1. Estimated cost per mile for following systems:
   - 600-volt bare conductor
   - 600-volt completely insulated
   - 2400-volt bare conductor
   - 2400-volt completely insulated
   - 4160-volt bare conductor
   - 4160-volt completely insulated
2. Estimated cross-section dimensions for each of the above systems.
3. Estimated impedance per mile for each of the above systems.

## TABLE 2. DESIGN CRITERIA FOR 4160-VOLT THREE-PHASE CONTACT RAIL (July 1963)

| | | |
|---|---|---|
| **Physical Arrangement** | | |
| Refer to Drawing | Z 806-E-1 | |
| Phase Spacing | 6 inches between center line of conductors | |
| **System Impedance** | | |
| Not to exceed 0.055 ohms/1000 feet per phase | | |
| Phase angle is unspecified | | |
| **Conductor** | | |
| Maximum Momentary Current (Full Offset) | | 60,000 amperes |
| Four-Second Current | | 37,500 amperes |
| Short-time Current | 1,750 amperes | |
| RMS Current | 1,000 amperes | See attached graph |
| Continuous Current | 500 amperes | |
| Contact Surface Width | 1/2 inch minimum | |
| Conductor Wear Depth | Sufficient for 42 million collector shoe passes | |
| **Insulation** | | |
| Insulation tests shall be conducted in accordance with ASA C29.1. | | |
| Manufacturer shall meet limits as specified below. Where limits for tests are unspecified below, manufacturer shall furnish results of such tests in addition to those specified. | | |
| Voltage Classification | 5.0 kv | Nominal 4160 volts |
| BIL (1.5 x 40 microsecond) (Full Wave Crest) | | 60 kv* |
| Low Frequency Test RMS (Withstand) | 1 Minute Dry<br>10 Second Wet | 21 kv*<br>20 kv* |
| Radio Influence Voltage (RIV) | | 500 microvolts** |

* ASA C76.1

** NEMA SG5.4-10

## TABLE 3. DESIGN CRITERIA 4160-VOLT THREE-PHASE COLLECTORS (July, 1963)

**Physical Arrangement**

| | |
|---|---|
| Refer to Drawings | Z 806-EE-1 |
| Phase Spacing | 6" between center line of conductors |

**Capacity**

| | |
|---|---|
| Maximum Momentary Current (Full Offset) | 60,000 amperes |
| Four-Second Current | 37,500 amperes |
| Short-time Current | 160 amperes |
| RMS Current | 100 amperes |
| Contact Surface Width | 1/2-inch minimum |
| Shoe Wear Depth | Sufficient for 25,000 miles of travel |
| Collector Mechanism Design Life | 250,000 miles or 3 years |

**Insulation**

Insulation tests shall be conducted in accordance with ASA C29.1. Manufacturer shall meet limits as specified below. Where limits for tests are unspecified below, manufacturer shall furnish results of such tests in addition to those specified.

| | | | |
|---|---|---|---|
| Voltage Classification | 5.0 kv | Nominal 4160 volts | |
| BIL (1.5 x 40 microsecond) (Full Wave Crest) | | | 60 kv* |
| Low Frequency Test RMS (Withstand) | | 1 Minute Dry | 20 kv* |
| | | 10 Second Wet | 20 kv* |
| Radio Influence Voltage | | | 500 microvolts** |

**Protection**

Collector mechanism shoe support arms and shoe bodies shall be either nonmetallic or be of metal coated with a durable insulating material in order to minimize the potential hazard of accidental contact by authorized personnel or flashovers between collectors during operation.

*ASA C76.1
**NEMA SG5.4-10

Adjacent to the collector stand was a blower that could supply to the collector under test a blast of air equivalent to 80-mile-per-hour speeds. The blower was equipped to supply a water spray to simulate environmental conditions from a fog to a driving rain, and to propel flying objects such as dust, dirt, small gravel, and dust from composition brake shoes directly on the collectors.

Three type KFK overhead crane current collectors, as shown in Figure 4 were initially purchased from the Ringsdorf Carbon Company for evaluation on test apparatus. These collectors were not designed for high speeds and proved to be unstable at speeds approaching 80 miles per hour. Subsequently, collector samples were designed and built for demonstration on the vehicle by H. K. Porter Company, Ohio Brass Company, and the Garrett Air Research Corporation. These collectors are shown in Figures 5 to 7 respectively.

All concepts mount the collector to the truck structure of the vehicle and all use copper-graphite material for the brushes. In the Ohio Brass collector, two pieces of fiberglass are used as the collector arms and also function as springs. Only rail collector relative motion in the horizontal motion can be attenuated. The brushes must overhang the rail sufficiently to maintain contact during the extremes of vertical motion. The same observation can be made regarding the H. K. Porter collector. However, the latter offers the advantage of double shoes riding on each rail, such that one can be in contact under certain dynamic conditions when the other has separated. The Garrett collector has the same feature plus the capability of rotating about a horizontal axis so as to absorb vertical motion.

Both the H. K. Porter and Ohio Brass collectors were successfully demonstrated and logged over 5,000 miles each without a malfunction. Initial runs on one test vehicle with newly installed trucks required relocation of the collector on the truck to a position where vertical motion was not so severe. Also, several failures occured as a result of rail problems. These will be discussed after the rails have been described. The Garrett collector was destroyed by a flash over when it was initially energized after mounting on the vehicle, making testing impossible.

Rail configuration for BARTD demonstration project was dictated by space requirements and let to the vertical rail alignment shown in Figure 8. Contracts were awarded to two manufacturers for 4 1/2 miles of each of their designs (See Figure 9). In the system developed by the H. K. Porter Company (known contractually as Type I), fiberglass-reinforced

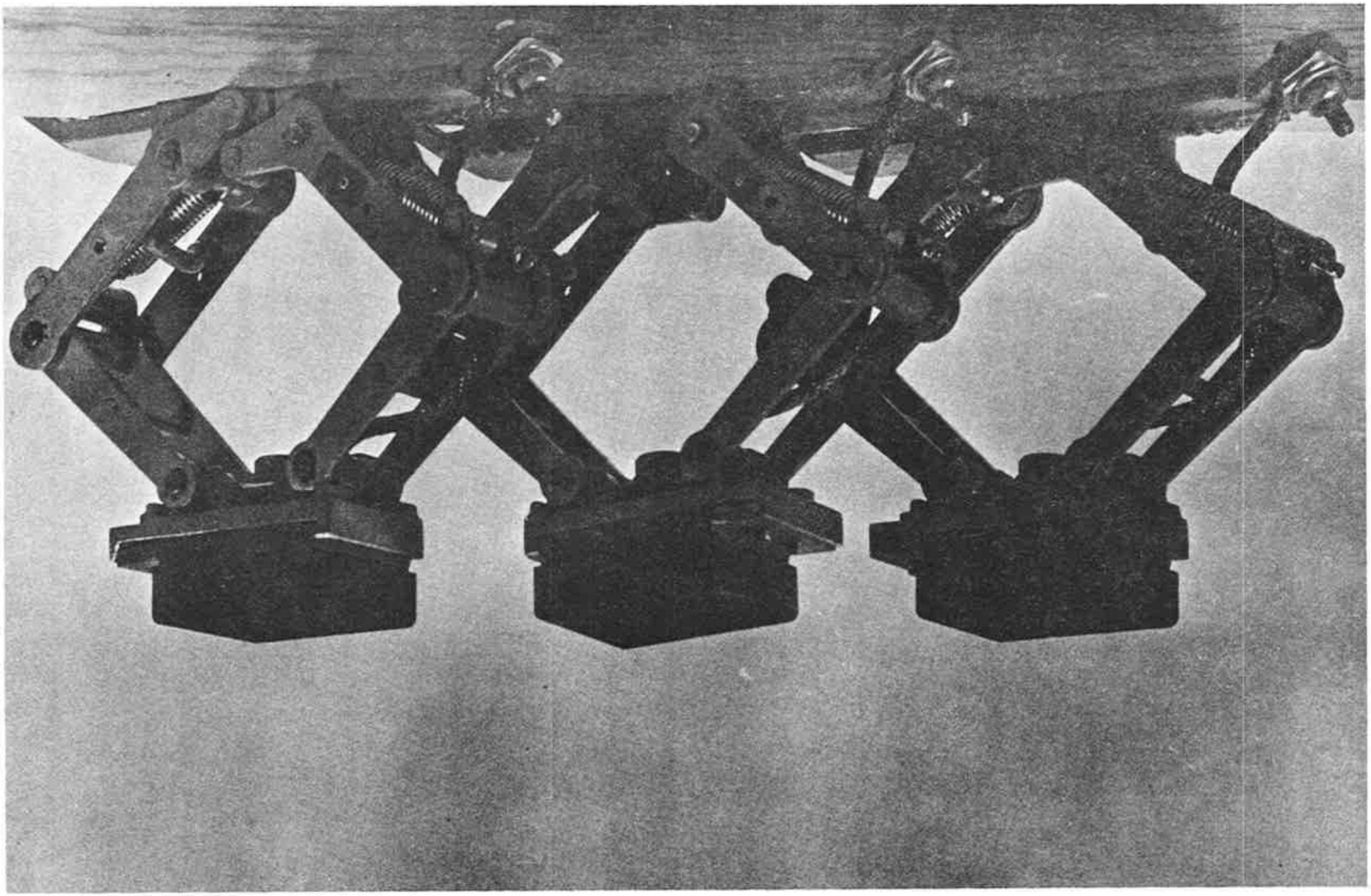


Figure 4. Type KFK Crane Current Collectors

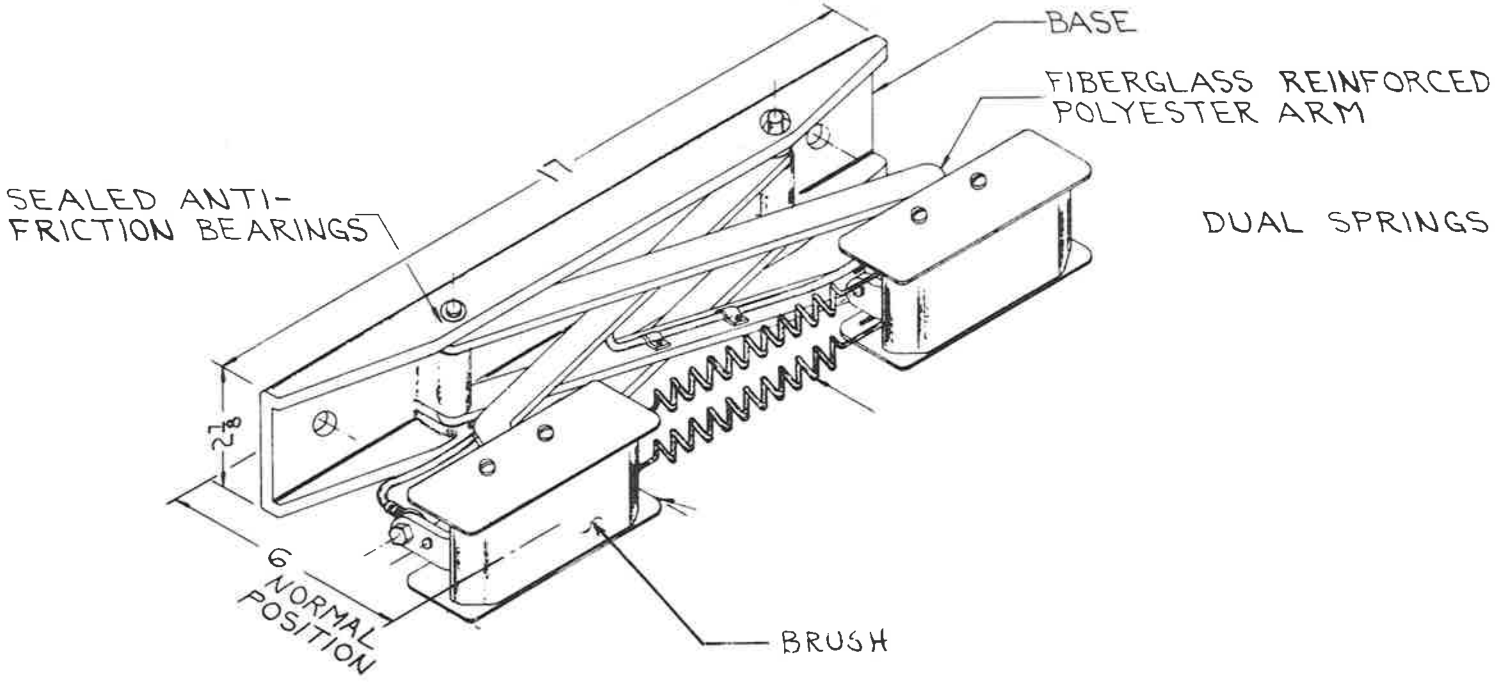


Figure 5. H. K. Porter Co. Collector

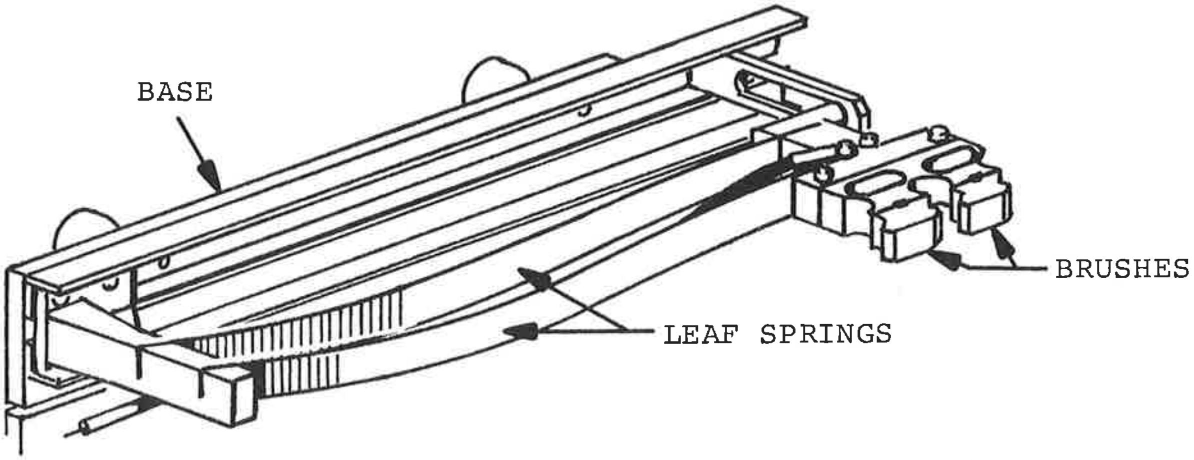


Figure 6. Ohio Brass Collector

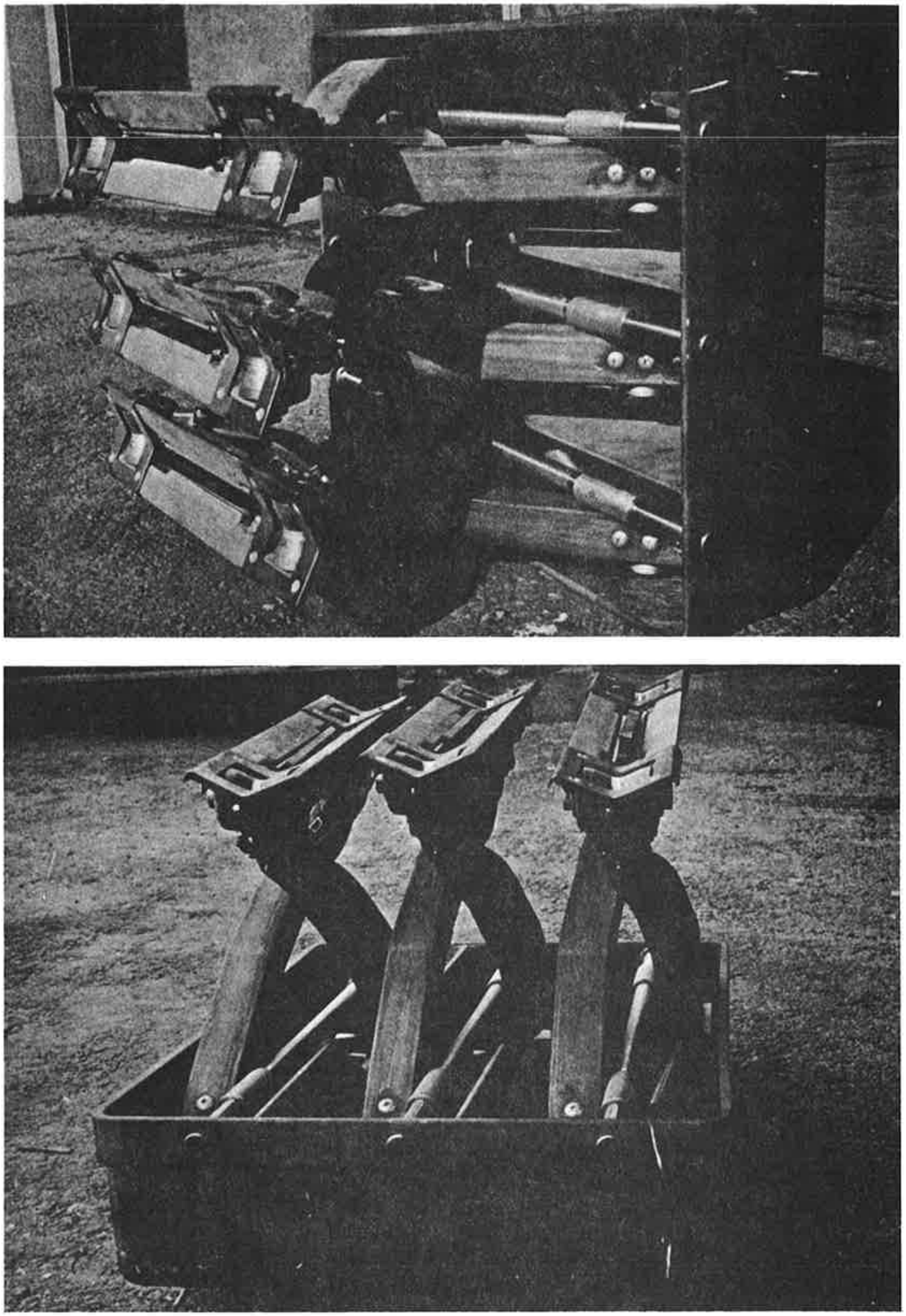


Figure 7. Garrett Collector

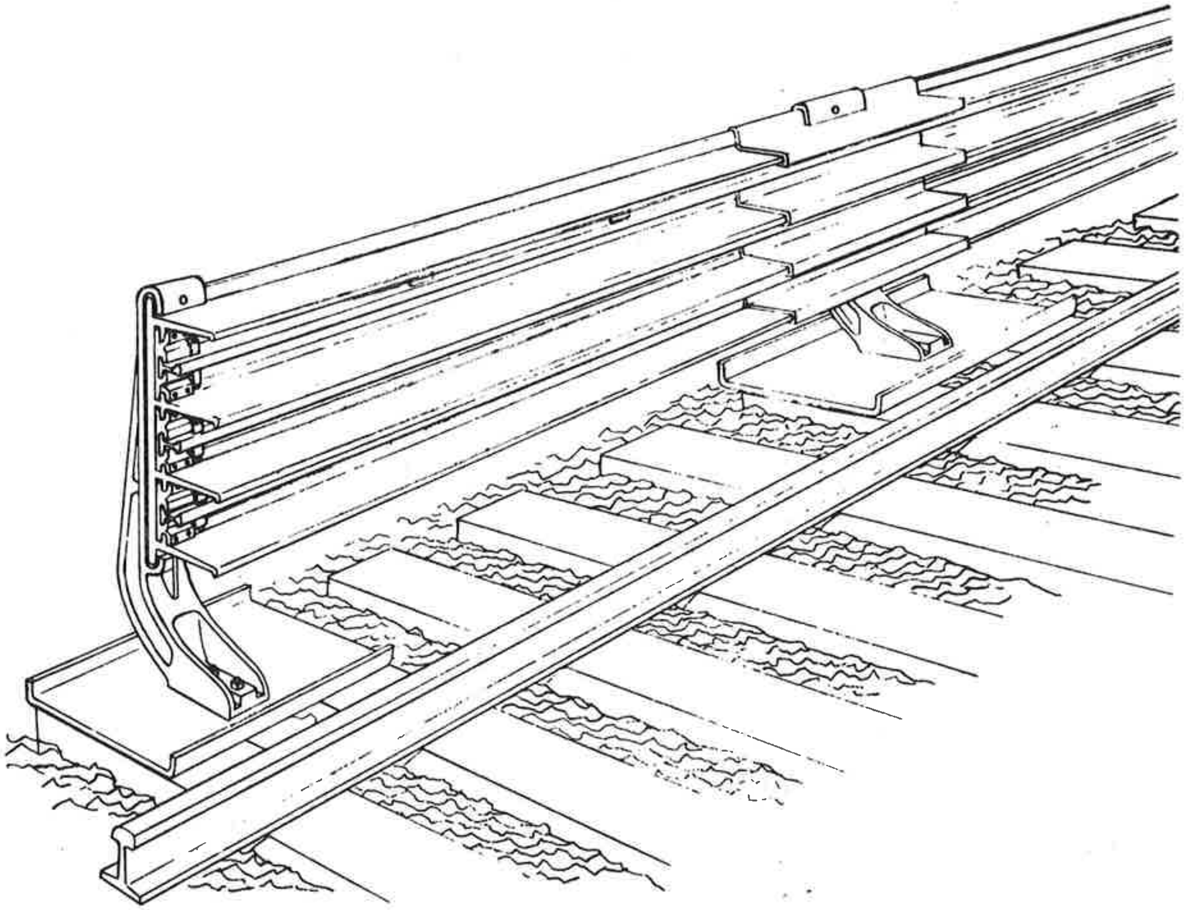


Figure 8. I.T.E. Improved Three-Phase ac Contact Rail Design

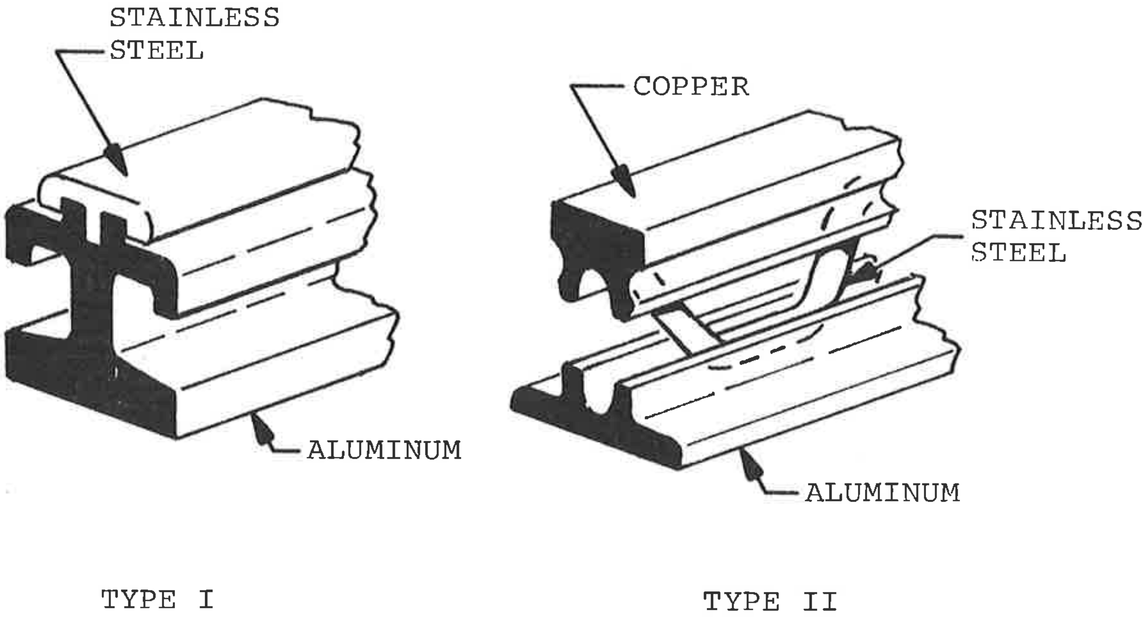


Figure 9. ac Rail Design

polyester was used for insulators, phase barriers, and personnel protection, on an aluminum rail which had a stainless steel cap for a running surface. In the system developed by the I.T.E. Circuit Breaker Company (known contractually as Type II), polyethylene was used for insulators, phase barriers, and personnel protection, with a rail made of a copper head, a stainless steel wire web, and an aluminum base.

Type I incorporates a composite rail section with high conductivity aluminum as its basic section; a stainless steel cap was mechanically locked and bonded, by means of a silver-filled epoxy, to the aluminum. The mechanical lock was secured by an interference fit on a center web, with the sides of the steel formed over or crimped to the aluminum. The structural element supporting the rail was a fiberglass-reinforced polyester molding that also acted as a basic insulation unit. The safety covers, which provided personnel protection as well as interphase separation, were made up of three separate pieces of fiberglass-reinforced polyester, each formed in an L shape. The basic units were assembled by the use of a single long bolt in an insulating sleeve, also used to amount the assembly to the cast aluminum support stanchions. The support stanchions were spaced on ten-foot centers and mounted on the track members (crossties, concrete invert, or aerial structure curb).

Type II consisted of a composite rail section with a copper hear or trolley wire, given mechanical rigidity by a corrugated stainless steel wire forming the rail web and mounted in an extruded aluminum base. The base of the rail was held in slots in polyethylene blocks. The rail was prevented from sliding in the blocks by a stainless steel clip passing between the loops of the wire web. The polyethylene blocks were held in grooves extruded in the polyethylene shape making up the safety covers and interphase barriers. The blocks and the barriers made up the complete insulation system. The polyethylene extrusion was supported by a glass-reinforced resin moulding bolted to channel iron support stanchions which, in turn, were fastened on ten-foot centers to the track structure (like Type I).

Problems were encountered during construction because the splicing on crossties were different than that specified for stanchions which supported the contact rails and covers. Covers had to be custom fitted and any gaps filled in. More significant was the problem of cover sag, primarily a thermal expansion problem. In some cases sag was enough to cause interference between the covers and collector arms. One collector failure occured as a result. The polyethylene used in the Type II covers is highly flammable and caught fire twice as a result of arcing. Carbon tracking was also of concern for the two covers used, since plastic insulators have not been used in the field long enough to obtain information on life expectancy. No conclusion was reached as to what carbon tracking specifications should be or whether the demonstrated covers where acceptable in this respect.

When the cars would run through an isolating rail gap or would diverge from the tangent track at a turnout or crossover, extreme arcing would occur, and many times the substation recloser would open as if a phase-to-phase or phase-to-ground fault had occurred. The arcing was particularly violent at car speeds under 30 mph and while a car was accelerating at maximum rate. The gaps and turnout areas, as well as the cars, were inspected closely and arc burn marks were found on the contact rail, on the running rail, and on the car underframe and trucks. Subsequent investigation showed that as a car collector leaves the contact rail with the car demanding power, the collector shoes pull beyond the phase barriers before the collector-to-rail arcs extinguish. Once past the barriers, the arcs develop into phase-to-phase or phase-to-ground faults.

Rail misalignment in Type I occured when the rails with ends cut on a 30° angle lengthened due to thermal expansion and displaced the joints laterally. This contributed to collector shoe wear and chipping. Type II rails exhibited more shoe wear than did Type I. This was attributed to the open rail joints (i.e. ends cut at 90°), the square corners of the rail head section, and the joint bars which extended to the top surface of the rail. A brush wear test using the Type I rail was run which indicated 1/2" thickness of brush would have a life of 20,000 car miles.

## D.C. POWER COLLECTION

Concurrent with the ac power collection demonstration, a dc power collection program was implemented. Initially the standard steel running rail set on porcelain insulators and a conventional paddle type collector were used for demonstrating the dc propulsion system. Subsequently, a 1,000 volt dc propulsion system was selected for the BART revenue vehicle, and development of a dc rail collector system became critical. The conventional collector sparked excessively at high speed and the steel rail, which weighs 150 pound/yard, and was cast in 39 foot sections, made installation difficult.

Figure 10 is a clearance diagram circulated to prospective manufacturers for the rail and collector. Only the conventional over-running rail arrangement was considered (under-running arrangements which are more complicated and more costly, are normally installed in areas subject to freezing, and side-running arrangements offer no particular advantages).

Four companies responded with collectors for the demonstration. In all five were evaluated.

- St. Louis Car Company - Conventional paddle type, total assembly weight, including fuse box and mounting plate, 180 pounds, cast steel paddle with metal coil spring providing vertical pressure, laminated wood insulation block.
- Cleveland Crane Company - Revised version paddle type collector total assembly weight, excluding fuse box, 102 pounds, malleable iron paddle with double fiberglass leaf spring.
- Insul-8 Company - Total assembly weight, excluding fuse box, 75 pounds, cast iron collector shoe mounted on a metal block support by two flat metal springs, fiberglass mount.
- Test Track Developed - Total assembly weight, excluding fuse box, 25 pounds, sintered carbon shoe collector mounted on four fiberglass leaf springs, fiberglass mounting plate.
- Ohio Brass Company - Paddle type collector, total assembly weight, excluding fuse box, 35 pounds, malleable iron paddle with rubber tortional spring providing adjustable vertical pressure, fiberglass mounts.

No conclusion was reached as to which collectors were acceptable. However, high speed films and current sharing tests indicated a lightweight, softly sprung collector with ten to fifteen pounds of shoe to rail pressure had the best tracking ability. Excessive shoe wear was noted where there was intermittent contact and severe arcing. Figure 11 shows the seven rails tested:

- Type 1 - A section of low carbon steel rail weighing 150 pounds per yard and set on porcelain insulators with a malleable iron cap and base. This rail system has been used in transit systems for the past 50 years and was used on the test track as a reference for comparison with the other systems. Type 1 rail was installed on all types of track structures.

- Type 2 - A bi-metallic rail that consisted of a high carbon steel tee and an aluminum extrusion. This rail

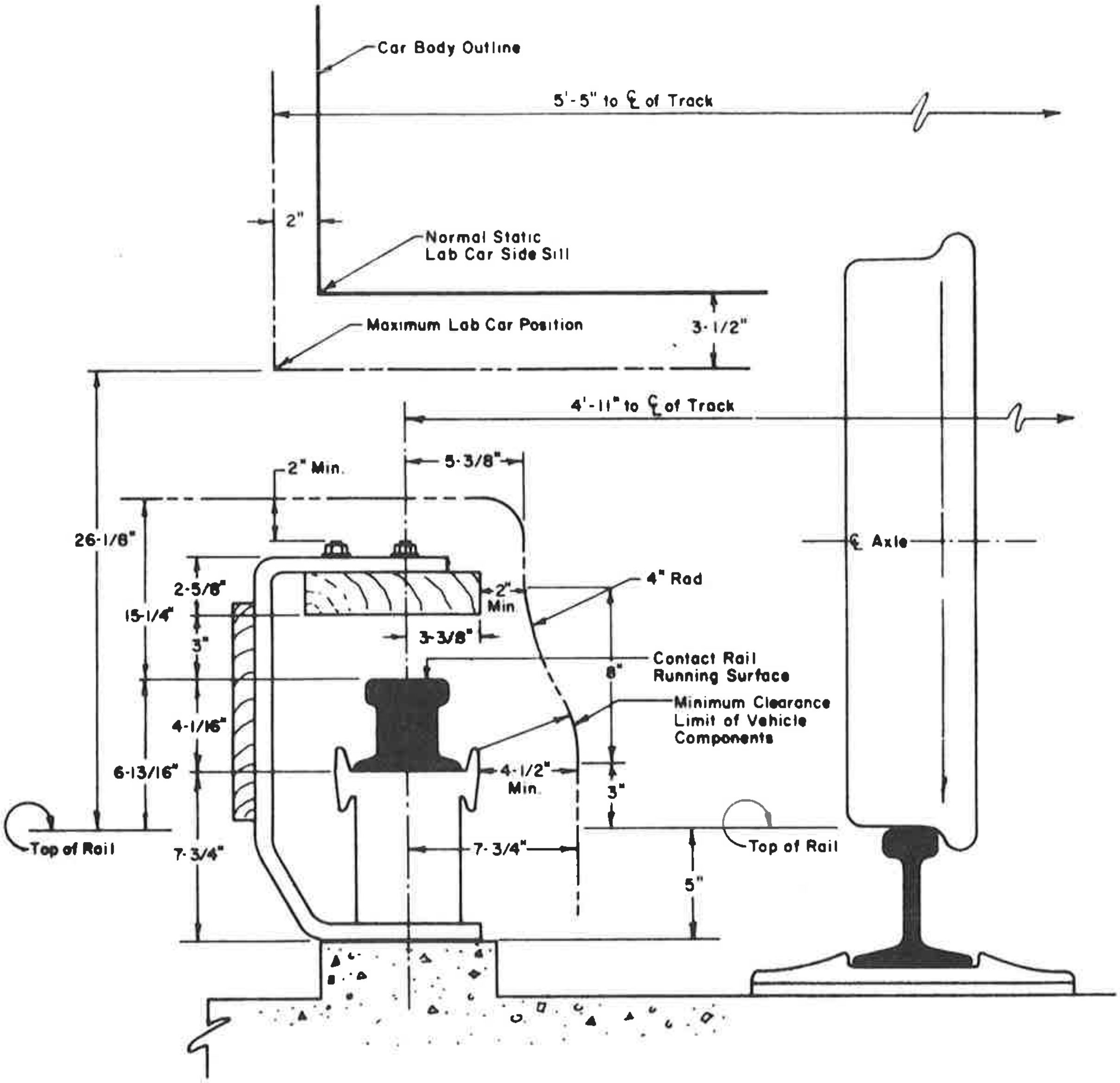
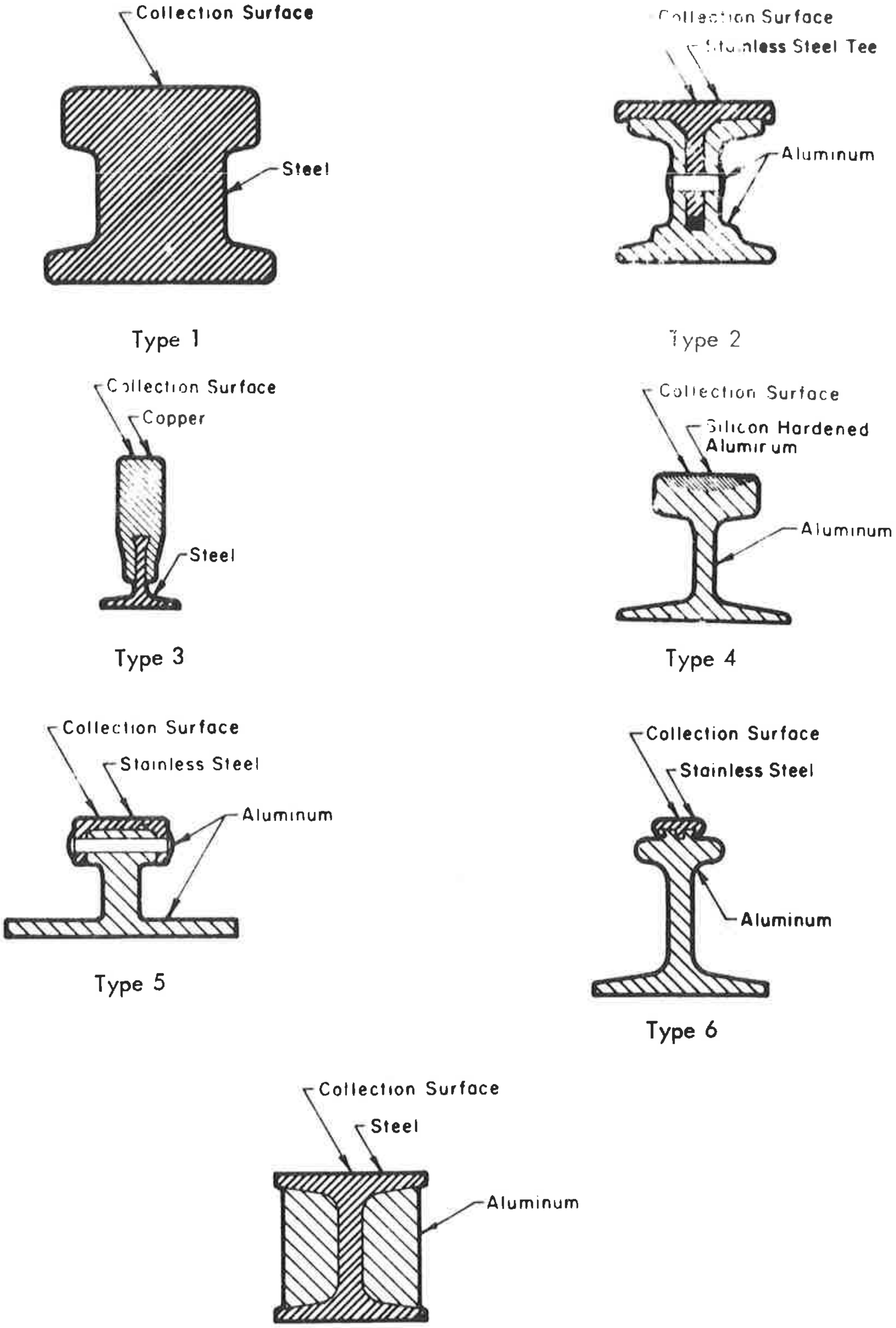


Figure 10. Clearance Diagram for dc Contact Rail



Type 1

Type 2

Type 3

Type 4

Type 5

Type 6

Type 7

Figure 11. dc Rail Design

weighs 38 pounds per yard and was developed from a lightweight rail used to power movable cranes. This rail was supported by a two-piece glass-reinforced polyester insulator designed expressly for this installation. The Type 2 rail was installed on a section of tie and ballast trackwork.

- Type 3 - A bi-metallic rail consisting of a copper head supported by a steel tee section. This rail weighs 30 pounds per yard and is supported by the same porcelain insulator as that used for Type 1 rail, with an adapter cap on the insulator. Type 3 rail was installed only on aerial structures.
- Type 4 - An all-aluminum rail section with the wearing surface of the head composed of a high silicon content aluminum alloy. The rail weighs 16 pounds per yard and is supported by a cylindrical glass-resin insulator with a bonded skirt that is bonded to a cast aluminum base and cap especially designed for this installation. Type 4 rail was installed on a timber-tied grade section.
- Type 5 - A bi-metallic rail consisting of an aluminum tee rail with a stainless steel cap mechanically fastened over the head of the rail. The rail weighs 23 pounds per yard and is supported by the same porcelain insulator assembly used for Type 1 rail. Type 5 rail was installed on aerial structures only.
- Type 6 - A bi-metallic rail consisting of a stainless steel cap bonded to an aluminum tee section. The rail weighs 17 pounds per yard and is supported by the same insulator assembly used for Type 4 rail. Type 6 rail was installed on a timber-tied grade section.
- Type 7 - A bi-metallic rail consisting of a high carbon steel tee and an aluminum extrusion. This rail weighs 15 pounds per yard and is supported by a porcelain insulator with a malleable iron cap and a precast concrete base. The Type 7 rail was installed on an aerial structure.

Tests indicated types 2 and 7 best met the requirements of light weight, high conductivity and low rate of surface wear. Insulators were a problem for several configurations, either being too weak to withstand lateral forces, or breaking away at the base under thermal expansion of the rail. Smooth run-on and run-off ramps were also found to be essential to prevent arcing and excessive shoe wear. Insufficient testing was performed to measure rail wear. However, the aluminum headed rail (Type 4) and the copper-headed rail (Type 3) exhibited accelerated wear characteristics. Corrosion of the bi-metallic rails, it was concluded, could be reduced to an acceptable rate.

## REVENUE VEHICLE

Sufficient tests were performed and enough data was collected during the Test Track program to determine the basic requirements for the final BART system. These basic requirements are shown in Appendix A, Design Criteria for the 1000 volt dc Contact Rail Assembly, and Appendix B, Design Criteria for 1000 volt dc Collector Assembly

# POWER COLLECTION - TRANSIT EXPRESSWAY MASS TRANSIT DEMONSTRATION PROJECT (REFERENCE 3)

The Transit Expressway vehicle resembles a bus and rides on four pairs of pneumatic tires, at speeds up to 50 mph. The roadway is 9360 feet long loop, principally elevated, which was constructed south of the Pittsburgh central business district for the purpose of determining public acceptance and demonstrating the technology. The system logged 21,316 vehicle miles during evaluation tests.

The primary power is 565 volt three phase alternating current at 60 Hz delivered to the vehicles via an array of three conductor trolley rails mounted along the inside edge of the right hand concrete track slab (See Figure 12). A matching set of collector brushes mounted beneath the vehicle and maintaining sliding contact with the power rails deliver power to an onboard step down transformer and the rectifier unit.

The current collector assembly is mounted on the guided axle frame in such a position that sliding contact between the brushes and the surface of the three power rails is maintained. To insure a continuous flow of power from the rails to the vehicle, there are two collector assemblies, one on each axle of the vehicle. Each of the three unit current collectors in a current collector assembly has two brushes (See Figure 13). Thus, there are four sliding contacts for each rail. To minimize the possibility of a phase-to-phase fault on the rails due to arcing at the brush positions, the unit collectors are mounted such that the center line of brushes on the center rail are five inches forward of the centerline of the brushes on the outer rails. The desired brush pressure as determined by tests is 13 pounds per brush. Vertical motion (±") between the axle assembly and power rails is permitted by using the leaf springs and a coil spring in the cylinder to maintain constant pressure. Lateral motion of ±1/8" is allowed since the brushes overlap the rail by 1/4" total.

Four different grades of brushes were tested in the following order:

1. R-507 Hard carbon without metal
2. W-828 Metal graphite
3. RM-1112 Metal impregnated carbon, low metal content
4. RM-130 Metal impregnated carbon, high metal content.

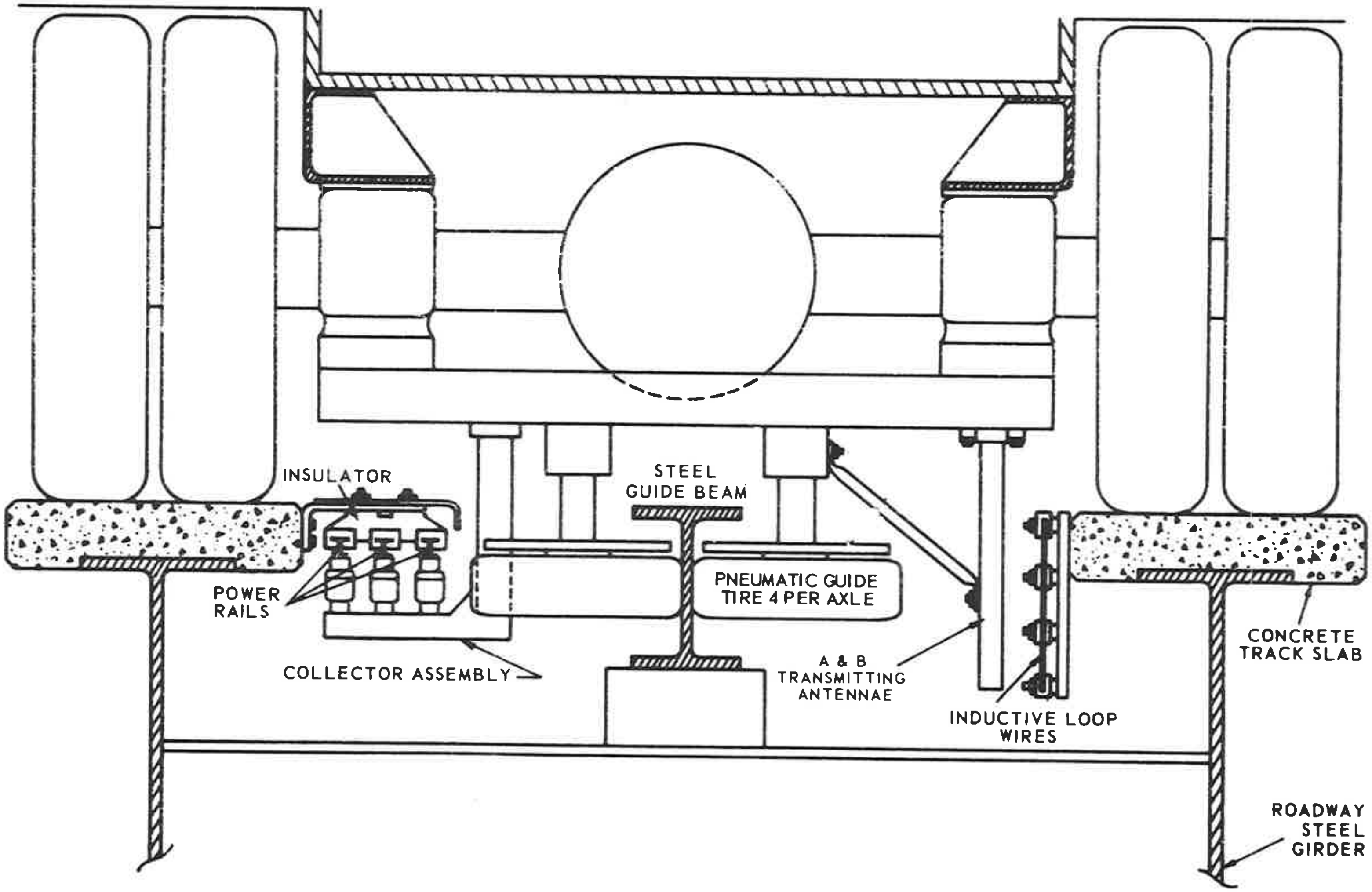


Figure 12. Transit Expressway Collector System

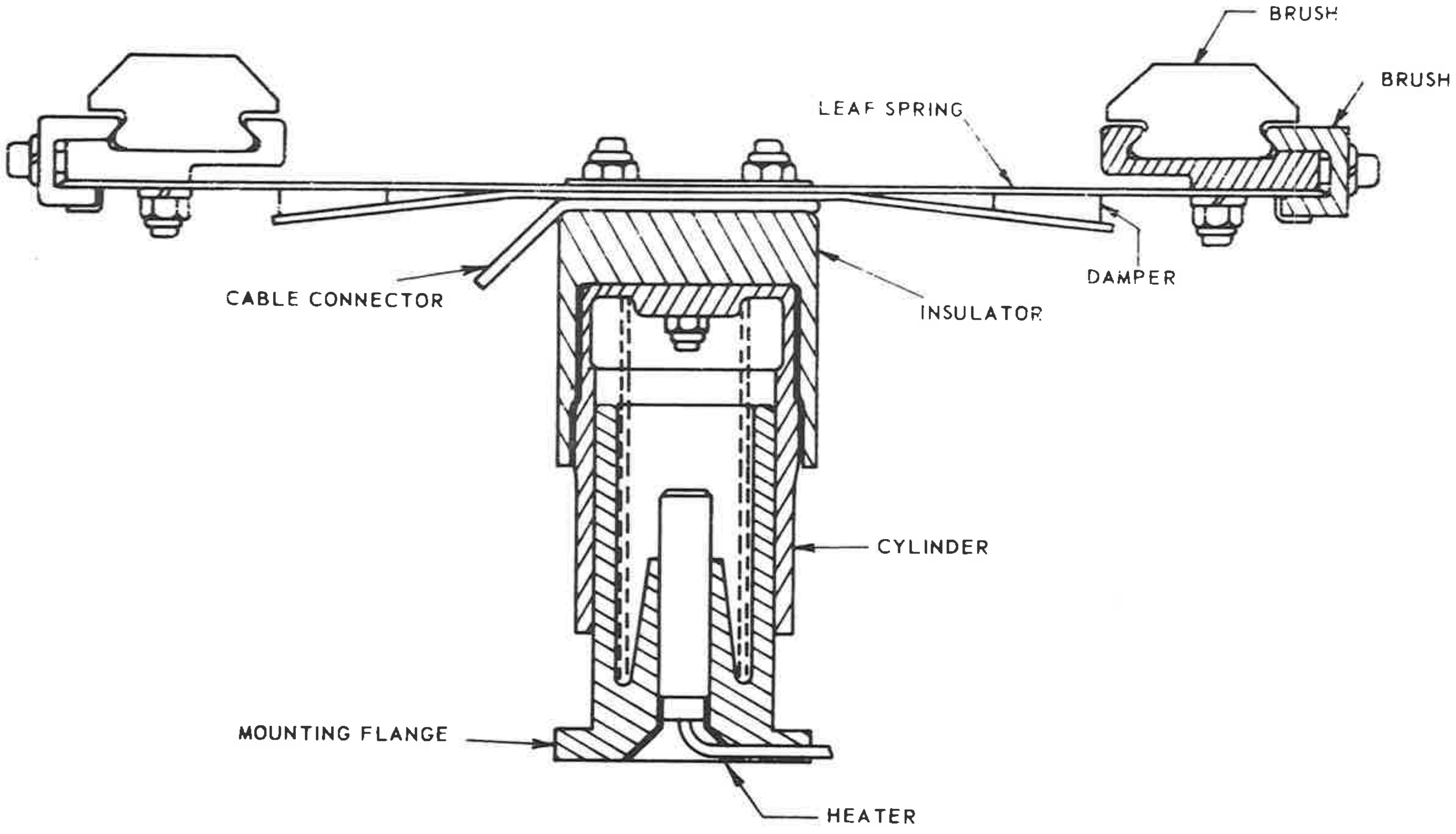


Figure 13. Transit Expressway Current Collector

Wear pattern improved with each grade. However, economics and quiet operation led to selection of R-507. Indicated service life for R-507 is 8,000 to 10,000 miles.

Arcing between brushes and rails was barely preceptible in normal operation. During ice or frost buildup, however, severe arcing occured at the collector brushes. During heavy rain hydroplaning of the brushes caused severe arcing. Installation of a cover over the entire power rail system appears to be the solution to these arcing problems.

Some earlier collector designs failed as a result of freezing of the cylinder. This resulted in broken insulators when the collector was unable to compensate for the ±1" relative vertical motion between the axle assembly and the power rails. This problem has been solved by inserting a heater inside the cylinder (See Figure 13).

Extruded copper rails with an "I" cross section are used on the South Park system with the exception of 120 feet of aluminum, clad with stainless steel. The copper rails are the equivalent of a 700,000 circular mil conductor and are in 20'-30' spans with an expansion gap at each connector. With the exception of a few 45° cuts for test, the ends of the rails are cut square. The three rails are mounted on suitably insulated brackets (Figure 14) which are bolted to the inside edge of the right hand concrete track slab (looking in the direction of travel). The rail spacing is 3-3/8" between centers and the underside rail width on which collector brushes slide is 1-1/4" leaving 2-7/8" spacing between the edges of rails. There are no barriers between rails and they are covered on top only at station platforms.

Insulating power rail support brackets are spaced at intervals of approximately 10 feet. In addition to the support brackets, insulating spacers (Figure 15) are used at points equidistant between support brackets to maintain rail separation particularly with large forces generated by short circuit currents.

One collector failure occured as a result of a rail which bowed with thermal expansion because the ends were held too tightly. This problem was overcome by applying an electrically conductive grease to the connectors used to maintain conductive continuity from rail to rail.

The effect of rail gap discontinuity on brush life has been a point of concern even though tests revealed no significant problem Acoustic noise and pulse type radio interference were observed to emanate primarily from the brushes

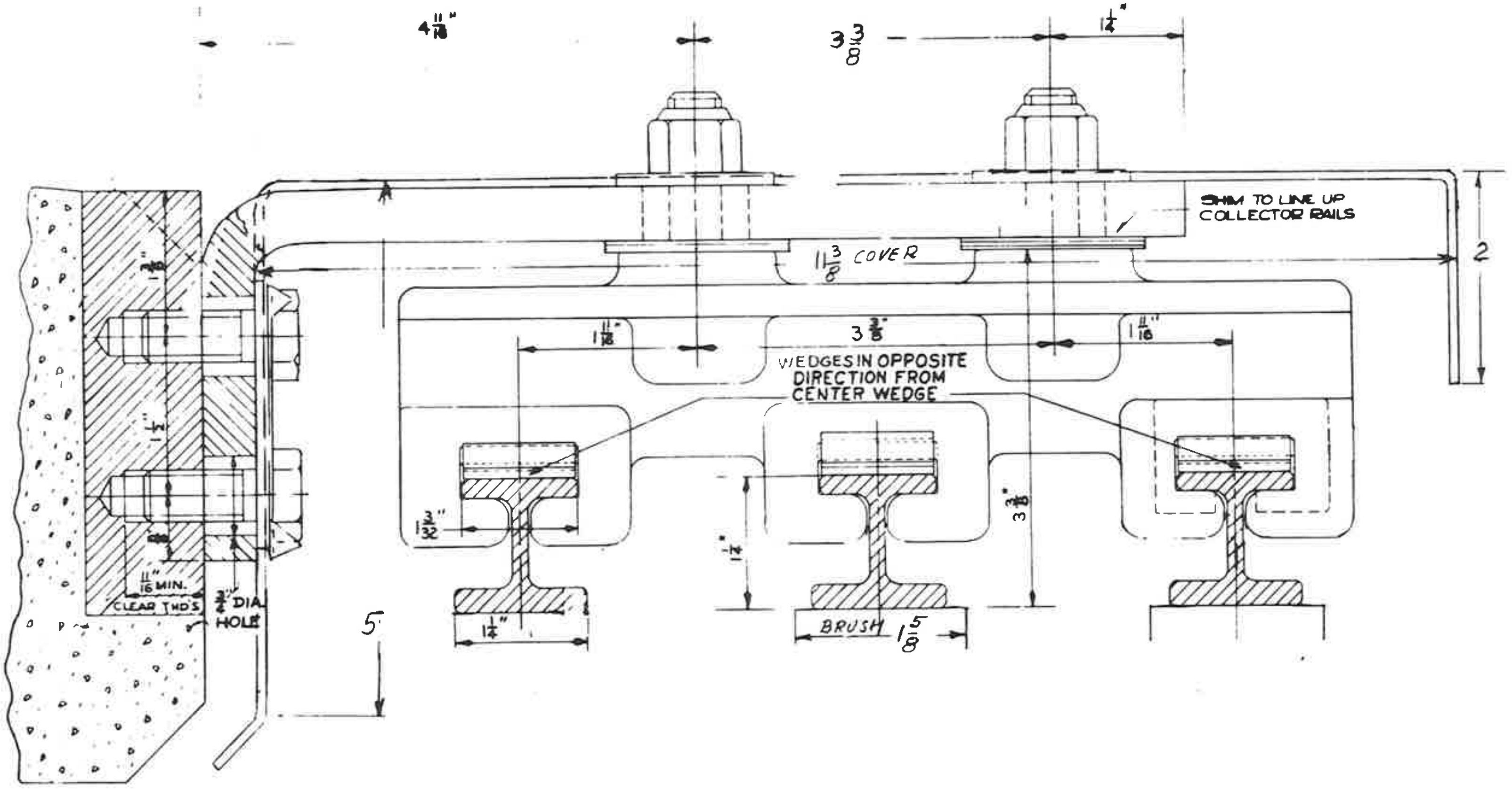


Figure 14. Mounting Bracket

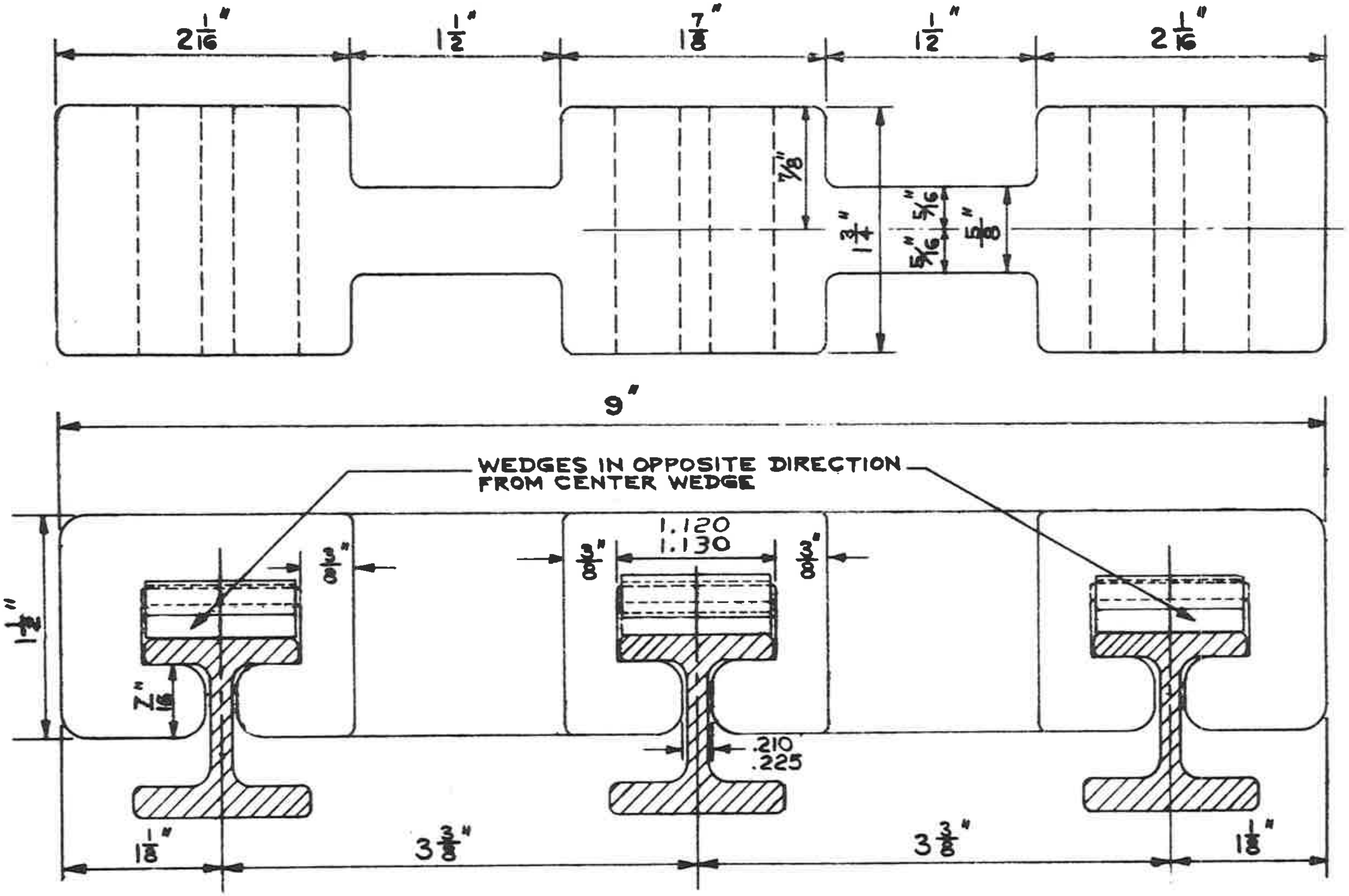


Figure 15. Insulating Spacers

crossing rail gaps. To minimize brush wear, acoustic noise, and radio interference on the revenue vehicle, it has been recommended that the power rail ends be cut vertically at a 60° angle with the axis of the rail, the terminal knife edge and the top diagonal edge be chamfered, and the working surface at the apex sloped gradually to eliminate any sharp vertical discontinuities.

Other recommendations made for a revenue vehicle are:

1. The present system of power distribution to the power rails comprises an ungrounded or isolated delta connection to the three phase rail conductors. This arrangement together with grounding brushes on the vehicles at stations was originally selected as one method of eliminating shock hazards. Further consideration now indicates certain advantages in the use of a corner grounded delta connection and accordingly this is recommended particularly for a higher voltage system. However, this will require modification of the vehicle couplers to provide good electrical conductance between couplers to handle unbalanced power circulation.
2. The present power rails have adequate cross section for any system, but the insulating material as installed will have to be improved for long term outdoor exposure.
3. The use of higher voltages will require some increase in spacing of the power rails together with the installation of continuous insulating barriers between the inner and the two outer rails.
4. The protective cover now installed over the power rails at stations should be continuous over the entire system. This is particularly important for a higher voltage system and on any system to reduce short circuit hazards due to debris falling across the rails or adverse weather conditions.
5. A method of positive locking of the power rails at one end of the expansion joint should be devised to prevent longitudinal motion and maintain the gap.
6. The spacing of power rail insulator supports and spacers must be designed to withstand the increased mechanical forces produced by the much greater short circuit currents involved with larger power supplies required for commercial systems.
7. For higher voltages, the current collector insulation problems resulting from snow and ice accumulations should be carefully studied.

# AEROTRAIN DEMONSTRATION VEHICLE

The Aerotrain is a LIM powered TACV which runs on 1.9 miles of test track in Gometz, France. Power collection has been successfully demonstrated on this vehicle at 120 mph by LeMoteur Lineaire, developer of the Aerotrain.

The primary power is 1,000 volt three phase alternating current at 50 Hz with a peak current demand of 1,500 amperes. Figure 16 is a sketch of the rail-collector cross section. This type of collector is said to be "captive" since lateral motion is restrained by the rails as it is pulled along by the vehicle.

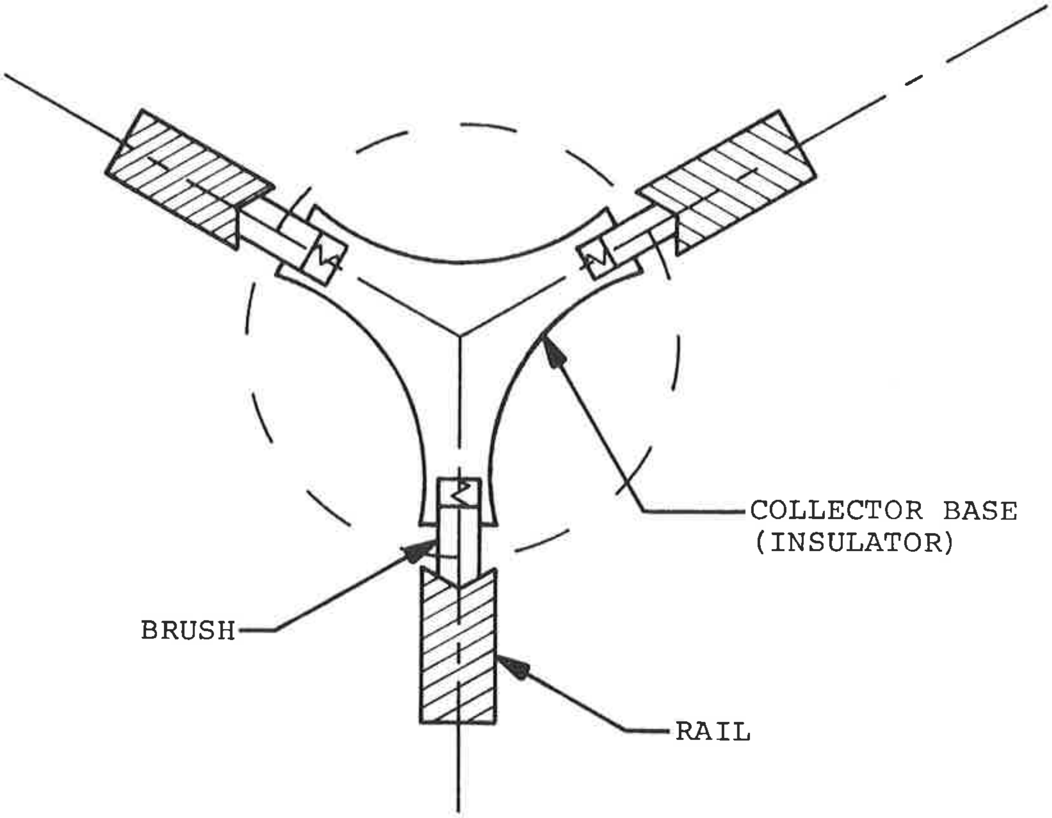


Figure 16. Schematic of Aerotrain Collector Cross-Section

# TRACKED HOVERCRAFT LIMITED (THL) TACRV

Construction of 3 miles of test track for the THL/TACRV is now underway at Earith near Cambridge, England. Speeds of 150 mph will be achieved with the TACRV, now in the detail design stage. There are plans to lengthen the track during the second phase of the program so that the design speed of 250 mph may be achieved.

Electrical power supplied from the wayside to the linear induction motor (LIM) for propulsion is 3 phase, 6,600 volt alternating current at 50 Hz with a maximum demand of 10 MVA. In addition to the 3 conductor rails used for supplying LIM power, 2 additional rails provide 3 kV direct current for powering the vehicle lift fans.

The collector being tested for the THL/TACRV consists of "caliper" assemblies, one for each power rail. Figure 17 shows schematically how a caliper slides on each side of the web of a rail with an "I" cross-section.

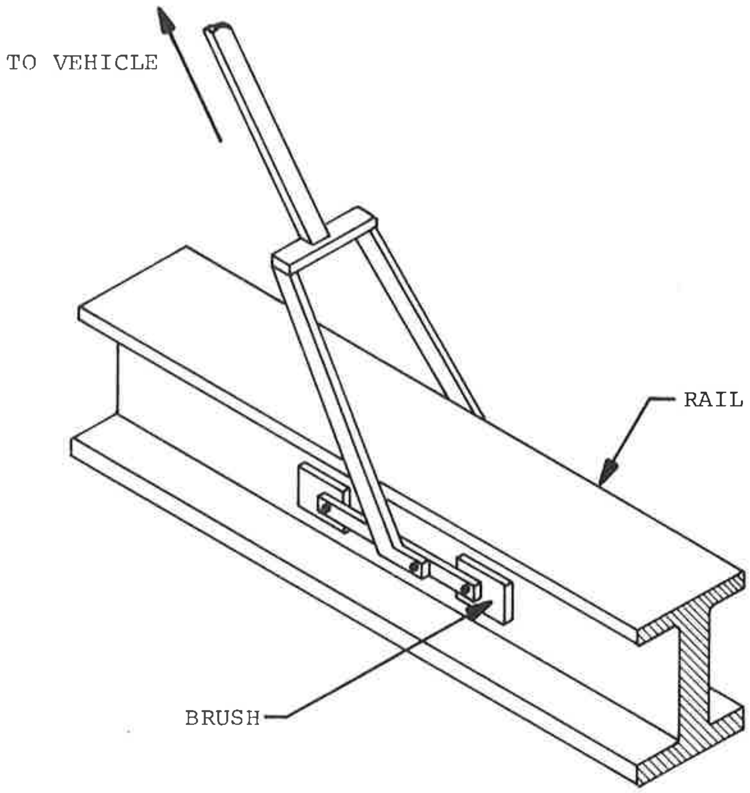


Figure 17. THL/TACRV Collector

# U. S. DEPARTMENT OF TRANSPORTATION TACRV (REFERENCE 4)

The U.S. Department of Transportation (DOT) is currently developing a tracked air cushion research vehicle (TACRV) to be run on six miles of guideway at the DOT test facility in Pueblo, Colorado. Initial demonstration runs are planned for Spring of 1972, with vehicle speeds of up to 300 mph contemplated.

Electrical power supplied to the LIM from the wayside for propulsion is 7,500 volt, 3 phase alternating current at 60 Hz. Power requirements are 17 megawatts for 3 minutes and 12 megawatts continuous. Stiff power rails will be used for distributing power along the wayside. The "captive" collector concept will be used although final configuration of the rails and collector will not be determined until initial testing of prototypes and materials is completed by the contractor.

# CONCLUSIONS

Choice of the captive collector concept to the British, French, and American tracked air cushion vehicles suggests that paddle type designs currently being used for subway operation are not adequate for handling the dynamics associated with higher speeds. This is further evidenced by the problems encountered in using the paddle design on the BARTD vehicle. On the other hand, there has been no use of active collectors in high speed vehicles, suggesting that the dynamic requirements can be handled by passive elements.

Design and installation of the power rail(s) appears to be the key to a successful power collection system. Proper alignment of rails sections that are cut diagonally at the ends can eliminate most arcing and chipping of the brushes. In the case of 300 mph vehicles, welded rails may be necessary. Run-offs and run-ons should be designed to minimize arcing. Rail supports should have sufficient strength to withstand the expected dynamic loads and heat expansion.

For collection at high speeds, avoidance of possible dynamic interaction between rail(s) and collector may be critical to maintaining contact. This problem has not been encountered to date and should be examined carefully along with wear of brushes and rails at higher speeds and higher current densities.

# REFERENCES

1. Magnus, Daniel E., "The Dynamic Behavior of the Third Rail Contact Shoe for High Speed Transportation," Proceedings Institute of Environmental Sciences, 1968.

2. San Francisco Bay Area Rapid Transit District Demonstration Project, Technical Report No. 7.

3. Transit Expressway, Report on Testing and Evaluation, February, 1967.

4. RFP No. DOT-FR-10002, U.S. Department of Transportation, Federal Railroad Administration.

# APPENDIX A

# DESIGN CRITERIA FOR THE BARTD 100-VOLT DC CONTACT RAIL ASSEMBLY (REFERENCE 2)

I. Physical Arrangement
  a. System shall be of the overrunning type.
  b. The Centerline of the contact rail shall be 26 inches from the gauge line of the near running rail. The top of the contact rail shall be 6-3/4 inches above the top of the running rail.
  c. The allowed contact rail clearance envelope is as shown on the drawings.
  d. No electrically energized parts shall project beyond the envelope of the safety cover.

II. Conductor
  a. Nominal system voltage is 1000 volts dc.
  b. DC Resistance shall be no more than .004 ohm/1000 feet at 40 C.
  c. Conductor shall be rated at 3000 amperes continuous with not more than a 30 C rise in temperature and shall be able to withstand 10,000 amperes for 30 seconds without developing hot spots or deformation.
  d. Maximum fault current will be 135,000 amperes for 100 milliseconds.
  e. Lateral force on the conductor under maximum fault conditions of 135,000 amperes will be approximately 380 to 400 pounds/foot.
  f. Conductor shall have a minimum wear depth sufficient for 10 x $10^6$ collector passes.

III. Insulator
  a. Creepage distance to ground shall be eight inches minimum.
  b. Insulator shall withstand 30,000 volts for one minute dry and 20,000 volts for ten seconds wet.
  c. If plastic materils are used, evidence of the following shall be shown

| Characteristic | Minimum Rating |
|---|---|
| 1. Arc Resistance | 150 seconds/ASTM D495 |
| 2. Track Resistance | Nontracking/ASTM D2303 |
| 3. Dielectric Strength | 300 VPM/ASTM D149 |
| 4. Flammability | Self-extinguishing/ASTM D635 |

  d. Spacing of insulators for the entire transit system shall be ten feet nominal
  e. Insulators shall be capable of restraining the contact rail under maximum fault conditions with a side loading of approximately 3800 to 4000 pounds, applied to the rail.

IV. Safety Cover
  a. The safety cover shall be designed to protect personnel from any accidental contact with the conductor or other electrically energized parts of the assembly while assuring unimpared passage of current collector.
  b. Voltage classification of the safety cover shall be 10,000 volts.
  c. The safety cover shall be of a self-extinguishing material.
  d. Proof of sufficient weathering and accelerated testing of the safety cover material shall be provided to permit an evaluation of life expectancy.
  e. The safety cover shall provide clearance for the collector of 3-1/2 inches above the top of contacr rail and 4-1/2 inches beyond the centerline of the contact rail. These clearances shall be maintained throughout the life of the assembly without interfering sags.
  f. The safety cover may deflect to the top of the contact rail when stepped on, if protection from electrical hazard is still provided. The safety cover shall not crack or break and shall return to original shape and position when weight is removed.

V. Rail Joints
  a. Shall be sufficient to hold rail ends in alignment under transit system ambient temperature changes of approximately 20 to 110 F.
  b. Provisions shall be incorporated in the design to permit connecting new rail sections to worn rail sections, maintaining the top surface in alignment.
  c. Conductivity of the rail joints shall be equal to the conductivity of the rail sections without joints.

VI. End Approaches
  a. Shall provide for the smoothe transition of the collector shoe onto the rail.
  b. Ramp slopes, if required, shall be not more than tangent two degrees.

VII. Expansion Joints
  a. Shall be capable of accommodating expansion and contraction of conductor under all anticipated temperature changes while allowing smooth passage of collector under all conditions.
  b. Shall be located so as to minimize lateral forces on insulator.
  c. Shall be capable of accommodating expansion and contraction of conductors on curves with various radii to 400 feet, minimum.

VIII. Anchors
  a. Shall be sufficient to maintain conductor in place under all conditions of traffic, grade, expansion, and contraction.

# APPENDIX B

# DESIGN CRITERIA FOR THE BARTD 1000-VOLT DC CONTACT RAIL ASSEMBLY (REFERENCE 2)

I. Physical Arrangement
  a. Collector motion and limits shall be as follows:
    1. Horizontal motion, parallel and longitudinal to rail, reversible, will be 0 to 117 fps with an average of 75 fps.
    2. Horizontal motion, lateral to rail will be ±1-1/2 inches maximum at frequencies of 0 to 2 Hz.
    3. Cyclic rotation of mounting in a horizontal plane will be one half degree maximum at 0 to 2 Hz.
    4. Vertical motion, relative to rail, will be ±1/2 inch nominal at 1 to 2 Hz.
    5. Extension beyond operating range will be 2-1/2 inches maximum below top of contact rail when off rail, adjustable.
    6. Mounting adjustment for wheel wear of truck will be +0, -1-1/2 inches.
  b. Collector shoe shall have a minimum wear depth sufficient for 25,000 miles of travel.
  c. Collector mechanism shall have a minimum design life of 250,000 miles or three years of service.
  d. Collector shoe shall track the contact rail with a minimum of bounce or arcing and shall be designed so that there will be a minimum of shoe bounce when running onto or off contact rail at speeds up to 80 mph (117 ft/sec) with ramp slopes of tangent two degrees or less.
  e. Collector mechanism shall permit the shoe to be folded clear of the contact rail without interference with the contact rail safety cover,or the collector shoe shall be easily removed in order to isolate a car from the contact rail.
  f. Collector mechanism shall be designed so that there will be a minimum of replacement or renewable parts.

II. Rated Capacities
  a. Collector shall be designed to carry 250 amperes continuously, 500 amperes for 30 seconds and 1000 amperes for five seconds.
  b. The collector shall be capable of withstanding a maximum fault current of 135,000 amperes for 100 milliseconds.

III. Insulation
  a. Shall be rated for a nominal voltage of 1000 volts.
  b. Shall withstand 30,000 volts for one minute dry and 20,000 volts for ten seconds wet.

IV. Protection

a. Collector mechanism shall be designed to minimize the potential hazard of accidental contact to personnel and flashover during service operation.

b. Collector mechanism shall contain its own protection devices, such as fuses.