SECTION 10 PROPULSION SYSTEM

10.01 GENERAL

A. The Propulsion System shall be the latest, state-of-the-art, microprocessor based, IGBT ac inverter type with internal fault monitoring and self-diagnostics, see Section 10.10. The system shall be service-proven in North American rail transit service of equivalent severity to that specified herein.

B. Each car shall be fitted with four (4), 3 phase, asynchronous, ac induction traction motors to power all axles on the car, and a complete control system for their operation.

C. Either a dual or single inverter propulsion system will be considered.

1. A dual inverter system shall accommodate wheel diameter variation of not less than 1% between wheels on a truck. There shall be no restrictions placed on wheel diameters between trucks.

2. A single inverter system shall accommodate wheel diameter variation of not less than 2% between all wheels on a car.

D. Traction inverters and control system shall be designed to permit operation of one (1) inverter with the other inverter disabled.

E. Motors, brakes, controls and all related equipment and apparatus shall be designed and manufactured to provide an adequate margin of capacity and safety for the operation intended. The system shall also be designed to prevent excessive maintenance or service interruptions under the weight and other specifications given herein along with the duty cycles specified in Section 2.02, D, and the operating and performance characteristics specified in Section 10.02, B.

F. The full integration of the various elements of the Propulsion System is the responsibility of the Contractor. The Contractor shall coordinate all aspects of the propulsion and braking systems to provide seamless operation of all suppliers' equipment.

G. Adequate protection shall be provided for all devices in the Propulsion System against voltage variations to be found on the CTA system and/or developed by the car equipment. See Section 9.01, B.

H. The Propulsion System shall provide continuously variable tractive effort control as specified herein.

I. Electric braking shall be the primary brake at all speeds. Electric braking shall be rheostatic and regenerative with priority being given to regeneration. Regenerative, rheostatic and friction brake systems shall be designed to individually meet the requirements of Section 10.02, B, 4. The friction brake design shall be capable of providing a minimum of two (2), "Maximum Service Brake", friction only stops, from 70 mph without damaging any equipment. Friction brakes shall supplement the electric brakes for the final stop.

10.01 GENERAL (Continued)

J. The friction brake system shall be controlled by the Propulsion System.

K. The Propulsion System shall regenerate into the third rail during electric braking so long as the third rail is receptive. Resistors shall be used for electric braking when the third rail is non-receptive.

L. EMI emissions of the Propulsion System combined with the emissions of all other operating systems on the car shall comply with Section 9.20. The Contractor shall submit as part of their proposal, lab and field EMI test data from an existing product extrapolated to the installation on the CTA vehicle to demonstrate the ability to achieve EMI/EMC compliance.

M. The Contractor shall perform an FMECA, see Section 9.20, D, on all Propulsion System circuits.

N. The Propulsion System, friction brake system, propulsion control and associated details shall be reviewed by the Engineer.

O. Fuses shall not be used in the propulsion power circuits unless otherwise agreed to by the Engineer.

10.02 OPERATING CONDITIONS AND PERFORMANCE REQUIREMENTS

A. Operating Conditions

1.	Average Voltage	550 Vdc
2.	New wheel diameter	28 inches
3.	Minimum number of cars in train	2
4.	Maximum number of cars in train	12
5.	Grade resistance	0

6. The train resistance shall be calculated using the Davis formula under the above conditions.

10.02 OPERATING CONDITIONS AND PERFORMANCE REQUIREMENTS (Continued)

B. Performance Requirements

The performance specified herein shall be accomplished with a fully completed and equipped married pair with a load not exceeding 1,500 pounds per car of personnel and instrumentation.

All performance requirements shall be achieved with a 550 Vdc third rail voltage.

For conditions below 550 Vdc third rail voltage, the base speed may be reduced proportionally to the voltage reduction, but maximum tractive effort shall not be reduced. For conditions below 500 Vdc third rail voltage, the maximum tractive effort shall be reduced to minimize under-voltage shutdowns. Operation under these conditions shall not cause damage to the equipment.

The propulsion system shall not adjust performance based on passenger loads.

1. Accelerating Capability

A two-car unit shall be capable of accelerating to a speed of at least thirty miles per hour (30 mph) in fourteen seconds (14 sec), and to a speed of at least sixty miles per hour (60 mph) in sixty seconds (60 sec) on level tangent track. This capability shall be achieved with a 550 Vdc third rail voltage and with the average propulsion current draw per car not exceeding 600A for a period of fifteen seconds (15 sec).

The cars shall have a balance speed under the same conditions of at least seventy miles per hour (70 mph).

2. Maximum Speed Limiting

Each car shall be equipped with Portable Test Unit (PTU)-adjustable maximum speed-limiting circuitry. Initial setting of the maximum speed-limiting function shall be fifty-five miles per hour (55 mph).

3. Minimum Speed Limiting

Each car shall be equipped with PTU-adjustable minimum speed-limiting circuitry for operation through the car wash and for other similar purposes. The low speed limiting mode shall be in effect when the Master Controller is in the “MINIMUM POWER” position. Initial setting of the minimum speed-limiting function shall be three miles per hour (3 mph).

10.02 OPERATING CONDITIONS AND PERFORMANCE REQUIREMENTS (Continued)

B. Performance Requirements (Continued)

4. Acceleration and Deceleration Rates

The rates shown below are instantaneous values and shall be continuously variable from maximum to minimum power and from minimum to maximum service brake. Maximum and minimum rates shall be PTU-adjustable.

Rates shown below shall apply to a dry, level tangent track and shall include all train resistance.

MASTER CONTROLLER POSITION	ACCELERATION/ DECELERATION RATES	COMMENTS
”MAXIMUM POWER”	2.8 ±0.1 mphps	During the constant rate portion of the performance curve.
”MINIMUM POWER”	0.3 mphps	PTU-adjustable from 0.3 mphps to 1.0 mphps.
”COAST”	------	Free wheeling.
”MINIMUM SERVICE BRAKE”	0.5 mphps 0.5 - 1.0 mphps	Electric Brake: PTU-adjustable from 0.3 mphps to 1.0 mphps. Friction Brake
“MAXIMUM SERVICE BRAKE”	2.8 ±0.1 mphps	From maximum speed to electric brake fade out then supplement by friction brakes to stop.
”EMERGENCY BRAKE”	2.8 ±0.1 mphps plus 2.5 ±0.1 mphps plus Track Brake	Electric Brake Friction Brake

Rolling resistance shall not exceed 0.3 mphps on each car measured individually.

10.02 OPERATING CONDITIONS AND PERFORMANCE REQUIREMENTS (Continued)

B. Performance Requirements (Continued)

5. Jerk Limit

The rate of change of acceleration and deceleration shall be limited under all conditions other than emergency braking. The rate of change shall be PTU-adjustable between 1.0 mphpsps and 3.0 mphpsps. The initially setting shall be 2.0 mphpsps.

6. Characteristic Curves and Simulations

The Contractor shall submit, pre-proposal, the following information to demonstrate an understanding of the operating and performance requirements of this Section and the duty cycles specified in Section 2.02, D:

a. Speed, power and acceleration/deceleration vs. time curves.

b. Line current, motor current and voltage vs. speed curves.

c. Tractive/braking effort per car, train resistance and acceleration/ deceleration vs. speed curves.

d. Duty cycle runs summary data showing motor RMS current, average speed and time.

e. All performance characteristics shall be calculated for a light car with a 1,500 pound load on level, tangent track and new wheels.

10.03 ACCELERATION AND BRAKING CONTROLS

A. General

1. The power electronics and controls for the solid state traction inverter unit(s) shall be housed in the Propulsion Control Unit(s) (PCU).

2. All Propulsion Control Unit enclosures and their internal arrangements shall be identical.

3. The Propulsion Control Units may share common control electronics, protective devices, input devices, and line filter or its elements. Shared components shall not be included in the Propulsion Control Unit enclosures.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

A. General (Continued)

4. Any equipment subject to damage from water, snow, ice, dirt, or heat shall be adequately protected.

5. All undercar equipment enclosures shall meet the requirements of Section 9.01, L, and Section 12.09.

6. The operating voltage range of all devices required by this Section shall be as described in Section 9.01, A, B, and C.

B. Control Electronics

1. Control electronics shall be microprocessor based and shall comply with Section 9.15, for microprocessor application and standards. Control programs shall be stored in non-volatile memory.

2. The propulsion control electronics shall be arranged in two (2) distinct levels:

a. An acceleration and braking control unit for each car (a car control unit).

b. A traction inverter/braking chopper control unit for each Propulsion Control Unit.

3. The control electronics shall receive commands from the Propulsion Control Network (PCN) as specified in Section 15.07, and interpret these commands for control of the traction inverters/braking choppers and friction brakes.

4. Train direction change shall be provided by phase rotation reversal. Reversal logic shall respond to trainline direction commands generated by the Master Controller reverser key in the active cab as specified in Section 10.08, C.

5. The Propulsion System shall self-protect from train direction changes while the train is in motion.

6. The control electronics shall continuously monitor critical parameters of the Propulsion System operation and detect and shall protect the equipment from incorrect or potentially damaging or hazardous conditions.

B. Control Electronics (Continued)

7. The control electronics shall perform diagnostic and fault monitoring for the Propulsion System, see Section 10.10. The control electronics shall communicate with the Control and Monitoring Network (CMN) as specified in Section 15.06, for the exchange of data.

8. The control electronics shall include wheel spin-slide protection and dead rail detection functions, see Sections 10.03, I, and 10.03, J.

9. The control electronics shall include an electronic odometer function with permanent non-volatile memory. The odometer shall be reset/disabled by the PTU only at the highest customer security level. The control electronics shall communicate the total number of miles accumulated by the car via the CMN to the Train Operator's Touch Screen (TOTS), specified in Section 15.09. The TOTS shall display car mileage to the nearest mile and shall have a minimum of eight (8) digits. The actual car mileage shall be PTU-readable.

10. Electronic control equipment shall be segregated from power equipment except for power semiconductor drive circuits.

11. Control circuitry and control voltage sources shall be optically or transformer isolated from power circuitry and high voltage sources.

12. The control electronics shall be securely mounted in environmentally protected enclosures with adequate provisions for maintainability and safety. Special attention shall be given to the design to provide easy access to, and installation and removal of control apparatus.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

C. Propulsion Control Units

1. The PCU shall have two (2) major elements:

a. The Traction Inverter.

The traction inverters shall convert the 600 Vdc into a variable-voltage, variable-frequency, 3 phase ac voltage, and shall provide this ac voltage to the traction motors. Torque developed by the traction motors shall be controlled by varying the output frequency and voltage.

b. The Braking Chopper.

The braking chopper shall modulate the electrical energy delivered to the braking resistors. During partial line receptivity, the braking choppers shall direct the excess energy to the braking resistors. The braking chopper shall operate to maximize the energy returned to the line.

2. Each PCU shall be capable of being cut out.

a. The PCU cut out shall be automatic for repeated system faults or manual by a cut out switch located in the operator's cab.

b. Cut out of one PCU shall not affect the operation of the car or any other system.

c. When a PCU is cut out, the motors for that PCU shall free wheel in either direction.

d. Cut out shall be annunciated on the TOTS in the active cab, see Section 10.09.

3. PCU enclosures shall be force-ventilated by blowers which take in air above the floor of the car, as specified in Section 10.06. High voltage elements shall be isolated from the cooling air stream.

4. IGBTs shall operate at no more than seventy percent (70%) of their breakdown capabilities.

5. IGBTs shall have a minimum design life of twenty years (20 yrs) under the duty cycles specified in Section 2.02, and performance specified herein.

6. The PCU shall be capable of operating continuously over the input voltage operating parameters, specified in Section 9.01, B.

10.03 ACCELERATION AND BRAKING CONTROLS (CONTINUED)

C. Propulsion Control Units (Continued)

7. The PCU enclosures shall meet the requirements of Section 9.01, L, and Section 12.09, A and B, except that they may be carbon steel in lieu of stainless steel. All low voltage wires shall be plug connected. Plugs shall be as specified in Section 9.02, J, unless otherwise agreed to by the Engineer.

D. Braking Resistors

1. Braking resistors shall be sized for continuous operation under the duty cycles specified in Section 2.02, D, and the brake rates specified in Section 10.02, B, 4, without any dependency on regenerative braking.

2. Type, configuration and arrangement of the braking resistors shall be selected and designed to meet the EMI/EMC requirements of Section 9.20.

3. The braking resistors shall be mounted under the car.

4. The braking resistors shall be convection cooled.

5. Heat from the braking resistors shall be so directed to prevent damage to adjacent equipment and cabling. Heat shields shall be provided, as required, to protect the car floor, air duct insulation, wiring and other equipment from resistor heat.

6. The braking resistors shall be protected from wheel wash.

7. The braking resistors shall be insulated from their frames and the frame insulated from the carbody.

8. Resistor grid insulators shall be of a design, material and arrangement, which are easily cleanable.

E. Input Filter

1. General

The PCUs shall be protected by input filter(s). The input filters shall be LC circuits with the resonant frequency such that the EMI/EMC requirements of Section 9.20, are met.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

E. Input Filter (Continued)

2. Filter Capacitors

a. Filter capacitors shall have a fifteen year (15 yr) minimum design life.

b. Input filter capacitors shall be provided with a charging contactor and charging resistor that shall limit charging current and input filter voltage overshoot to values that will not cause failure or deterioration of any car components or nuisance activation of carborne or wayside protective devices. The charging curve, current vs. time shall be submitted, pre-proposal, for review by the Engineer.

c. Controlled discharge circuitry shall be provided to automatically discharge the capacitors to less than 50 V in less than ten seconds (10 sec) when any hinged cover of the enclosures containing high voltage capacitors or equipment connected to them is opened. The braking chopper may be used for this purpose.

d. The capacitors shall have permanent parallel resistors which shall discharge the capacitors within twenty minutes (20 min), independently of the controlled discharge circuitry.

e. All doors and covers of the enclosures containing high voltage capacitors or equipment connected to them shall have labels warning of the hazard from charged capacitors.

3. Filter Inductor

a. The filter inductor shall be mounted under the car and shall be adequately shielded.

b. The filter inductor shall be mounted on insulators.

c. The filter inductor shall be adequately protected from wheel wash.

d. The filter inductor coils shall be treated to be impervious to moisture, as specified in Section 9.01, M.

F. High Speed Circuit Breaker

1. The Propulsion System shall be protected by a High Speed Circuit Breaker (HSCB).

2. Incoming 600 Vdc power to the Propulsion System and outgoing regenerated power shall pass through the HSCB.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

F. High Speed Circuit Breaker (Continued)

3. The HSCB shall be sized to handle its continuously rated current and to interrupt the maximum fault current without damage to itself or surrounding equipment.

4. The HSCB shall be mounted in an adequately ventilated, insulated compartment, and shall have secondary insulation. The arc chute for the HSCB shall be specifically designed to contain the arc and vent into the ventilated enclosure.

5. The cover(s) for the HSCB enclosure shall be easily removable without disturbing the arc chute. Cables entering the HSCB enclosure shall be carried in watertight fittings. No direct air path shall exist from the HSCB enclosure to any other enclosure.

6. Low voltage interlocks shall be completely isolated and insulated from 600 Vdc circuits.

G. Line Contactors

1. A line contactor shall be provided for each PCU to connect and disconnect it from the primary power supply during normal operations and isolate a failed PCU.

2. The line contactor's capability shall be coordinated with HSCB capability.

3. The line contactors shall be capable of interrupting current in both directions.

4. The arc chutes for the line contactors shall be designed to contain the arc and vent into an adequately ventilated enclosure or to vent outside their enclosure.

H. Electric Braking

1. Electric brake shall be rheostatic and regenerative with priority being given to regeneration.

2. Electric brake rates shall be continuously variable as specified in Section 10.02, B, 4.

3. The electric brake control system shall continuously monitor line voltage on each inverter cycle, shall supply to the line the maximum amount of energy possible, and shall divert excess energy to the braking resistors.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

H. Electric Braking (Continued)

4. When regeneration is not possible or is disabled (by PTU), electric brake energy shall be dissipated by the braking resistors as specified.

5. Maximum line voltage during regeneration shall be PTU-adjustable from 650 Vdc to 800 Vdc. Initial setting shall be 750 Vdc at the third rail.

6. Failure of electric braking shall result in the friction brake system automatically providing the requested braking effort as specified in Section 10.02, B, 4.

I. Rail Gap and Dead Rail Protection

1. A rail gap/dead rail detector shall be provided on each car. The detector circuit shall detect rail gaps and sudden loss of third rail power.

2. The detector shall prevent current flow from the car into a section of dead third rail. Current flow shall be interrupted by disconnecting each PCU from the car current collectors. See Section 9.01, P.

3. The detector shall incorporate a continuous or regular self test function to ensure its integrity.

J. Wheel Spin and Slide Protection

1. The Propulsion System shall incorporate a spin-slide detection and correction function for protection against wheel spins in acceleration and against wheel slides in braking.

2. The spin-slide function shall take maximum advantage of the inherent slip correction characteristics of the ac drive to minimize spin-slide protection intervention.

3. Tractive and electric braking effort during wheel spin/slide correction shall be modulated on a per inverter basis. Slide protection for friction brakes shall be on a per-car basis.

4. Random and synchronous wheel spins and slides shall be detected at all speeds in acceleration and braking.

5. The wheel spin-slide function shall operate with all wheel sizes, new through condemning, and shall periodically self-calibrate wheel speed to compensate for wheel wear.

J. Wheel Spin and Slide Protection (Continued)

6. At a coefficient of adhesion of 0.05 or greater, the efficiency of the wheel slip system shall be at least 80 percent (80%) in acceleration and braking over the speed range between maximum speed and 3 mph.

   The wheel slide efficiency shall be defined as the ratio of the actual braking rate to the theoretical braking rate from brake entry speed to a lower speed. The spin efficiency shall be defined as the ratio of the actual accelerating rate to the theoretical accelerating rate, from an initial speed to a higher speed. The theoretical distance rate is that which is obtained by continuously utilizing the available track adhesion. Efficiency shall be calculated over the slip-affected portions of operation.

7. Upon detection of a spin the Propulsion System shall quickly, without jerk limit, reduce the tractive effort. Power to the motors shall not be reduced excessively, but sufficiently so that the subsequent increase in tractive effort will be met by increasing adhesion in order to prevent damage to the wheels. As soon as spin is corrected, the tractive effort shall be increased at a rate consistent with achieving the maximum performance with jerk limit.

8. Upon detection of an incipient slide (slip) the Propulsion System shall quickly, without jerk limit, reduce the braking effort and apply the track brakes. The braking effort shall not be reduced excessively, but sufficiently so that subsequent increase in braking effort will be met by increasing adhesion in order to prevent slides and resulting damage to the wheels and to minimize stopping distance. As soon as the condition is corrected the track brakes shall be de-energized and the electric braking effort shall be increased at a rate consistent with achieving the maximum performance without exceeding the specified jerk limit. The track brake function during wheel slip-slide correction shall be PTU-selectable.

   The wheel slide function shall be user-selectable. Selection shall be “CONTINUOUS” and “TIME-OUT”. Time-out adjustment shall be between zero and twenty seconds (0-20 sec) and shall be initially set at five seconds (5 sec). After time out, full requested braking effort shall be applied. The time period shall be adjustable by PTU. Final settings shall be determined on the prototype cars.

9. Activation of the wheel spin-slide function during emergency brake applications shall be user-selectable and shall initially be set “ON”.

10. Failure of the wheel spin-slide system shall not prevent cars from responding to commanded tractive and braking efforts.

10.03 ACCELERATION AND BRAKING CONTROLS (Continued)

K. Cab Signal Interface

1. General

The Propulsion System shall interface with the cab signal system as specified in Section 13.03, Section 13.05 and Section 13.23.

2. Coast Contactor

The Propulsion System shall include a Coast Contactor (CC) to interface with the ATC System. Coast command shall be accomplished by de-energizing the CC. Contacts of the CC shall be in series with the Power Control Relay contacts specified in Section 6.05, A. Auxiliary contacts, or other means reviewed and agreed to by the Engineer, shall be provided on the CC to give a feedback signal to the ATO sub-system of the ATC System to indicate the status of the contactor. If auxiliary contacts are used, they shall be loaded with sufficient current to burn through any corrosion that may accumulate in order to ensure a reliable status indication.

3. Overspeed Penalty Brake

The Propulsion System shall apply maximum service brake rate when the cab signal system requests a penalty brake application as specified in Section 13.03. Overspeed penalty brake application shall be accomplished by de-energizing the Dead Man Relay or its equivalent.

L. Door Control Interface

The Propulsion System shall interface with the door control system, as specified in Section 6.05, A, to inhibit propulsion while any side door in a train is open or unlocked.

M. Smart Card Interface

The Propulsion System shall be inhibited until receipt of a valid Smart Card login. This feature shall be PTU-selectable. See also Section 15.08.

10.04 KNIFE SWITCH

A. The main knife switch shall be of the single-pole, double-throw type.

B. In the normal operating position, the 600 Vdc supply shall be connected to the main motor circuits and to the auxiliary circuits, including 600 Vdc trainline, through separate contacts. In the non-operating position, the switch shall connect the auxiliary circuits to a 5/8-inch diameter split test plug onto which a 600 Vdc jumper may be connected to permit operation of the auxiliaries without 600 Vdc on the third rail shoes.

10.04 KNIFE SWITCH (Continued)

C. The switch shall be equipped with quick break blades as required. A fuse holder and fuse shall be provided in this switch to protect the wire to the auxiliary circuits. It shall not be possible to close the cover on the switch if it is in the non-operating position. The switch box shall be adequately protected from wheel wash to protect the switch in the event the car is operated with the switch box cover open. The switch shall be mounted in such a manner that the handle can be reached from either a pit or from along side the car. The test plug shall be arranged for use from alongside the car.

D. The main knife switch shall be mounted in a fiberglass box with a cover equipped with compression spring draw latches. The switch and its box shall be supplied by the manufacturer of the Propulsion System.

10.05 TRACTION MOTORS

A. General

1. Each axle shall be individually driven by a 3 phase asynchronous motor of the squirrel-cage type of appropriate rating for the performance and operating conditions specified in Section 10.02, and the duty cycles specified in Section 2.02.

2. The traction motor shall be designed in accordance with IEC Standard 349-2, Electric Traction-Rotating Electrical Machines for Rail and Road Vehicles-Part 2: Electronic Converter-Fed Alternating Current Motors. The motor shall have a safe speed that meets the requirements of Section 6.3 of IEC 349-2.

3. All traction motors shall be identical and fully interchangeable.

4. The traction motor may be force-ventilated or self-ventilated. Force-ventilated traction motors shall be ventilated by blowers which take in air near the roof of the car, as specified in Section 10.06. Traction motors shall comply with noise requirements of Section 16.02.

5. The traction motor shall be designed to accommodate wheel diameter difference requirements of Section 10.01, C, over the full range of wheel wear.

B. Details

1. The maximum safe motor speed shall not be less than 6,000 rpm.

2. Rotors and cooling fans shall be dynamically balanced so that the maximum unbalance of a rotor or a rotor/cooling fan assembly shall be within 0.5-inch-ounce. Balancing shall be with permanently attached ferrous metal correction weights.

10.05 TRACTION MOTORS (Continued)

B. Details (Continued)

3. The traction motor coupling flange, if shrunk in place, shall be provided with locking washer and hex head nut.

4. The motor shall operate within the Class H temperature range designated in Table 1 of IEEE Std. 11-2000 with Class C winding insulation. Motor temperature may increase to the thermal class of the insulation under the conditions specified in Sections 2.02, D, 3, 4 and 5. Motor over-temperature protection shall be provided. Sensors embedded in the motor winding shall not be used.

5. The completed motor frame with insulated stator coils shall be vacuum-pressure impregnated (VPI).

6. Motors with stator core stacks that are not completely shielded shall have no discontinuities in the stator flux flow.

7. Motor bearings shall have grease fittings so located as to allow convenient servicing from below with the motor mounted in the truck.

8. Motor bearings shall be insulated to prevent current flow through them.

9. Motor disconnects shall be located such that they shall be easy to disconnect with the motor in the truck and the truck under the car and shall also be securely retained. The arrangement of cables, cleats and disconnects shall be demonstrated on the truck mock-up.

10. The motor interconnect arrangement with the PCU shall be reviewed by the Engineer and demonstrated on the underfloor mock-up.

11. The motor-gearbox coupling shall be grease lubricated and similar to that used on CTA's 3200 Series cars. The arrangement shall be reviewed by the Engineer.

10.06 PROPULSION SYSTEM VENTILATION

A. Force-ventilated traction motors shall be ventilated by blowers which take in air near the roof of the car. One (1) blower shall be provided for each truck to cool two (2) traction motors. Output air from these blowers may be shared to supply cooling air to PCUs or a separate blower may be provided for each PCU taking air from above the floor.

B. The air ducts in the sides of the car shall be totally segregated from the door pockets and sealed to prevent drawing air from the door pocket or car interior. The widened area adjacent to the door pockets and the narrowed windows are shown on CTA Drawing R-1-606, Page DR-1. Air ducts shall have appropriate clean-out openings.

10.06 PROPULSION SYSTEM VENTILATION (Continued)

C. The blowers shall be supported on vibration absorbing mounts and shall be easily accessible for servicing.

D. Blower motors shall be 3 phase 230 Vac, heavy duty, TEFC, powered by the car's 230 Vac supply through circuit breakers P51 and P52. Additional circuit breakers shall be provided, as required, see Section 9.01, J, and Section 12.11.

E. In the event of a ventilation failure, power shall be removed from the affected system; however, one more stop with electric brakes shall be possible. Upon the request for power, a Blue Light trouble indication shall occur and require the affected system(s) to be cut out.

F. The carbody to traction motor flexible ducts shall incorporate mechanical means to prevent collapse when fully expanded or pulled off axis. The ducts shall be impervious to the heat, dirt, snow and other elements found under the cars and shall be reviewed by the Engineer.

G. A filtering arrangement shall be included to filter the air before it enters the blower. The filter element shall be of a washable type impervious to water and caustic cleaners. The filter shall be at the air inlet in the side of the carbody and shall be as shown on CTA Drawing R-1-582, Page DR-18, unless a larger size is required to minimize pressure drop. The filter shall be mounted in a frame behind the air grille mounted in the carbody.

H. The ventilation-filtering scheme and the ducting arrangement shall be reviewed by the Engineer.

10.07 FRICTION BRAKES

A. Track Brakes

1. Four (4) electromagnetic track brakes reviewed by the Engineer shall be provided on each car. Each truck shall be equipped with two (2) electric track brakes connected in parallel. Track brakes shall be controlled by a suitable push button switch, with a solid red plastic push button, mounted on the operator's console. The button shall be mounted on a 0.125-inch thick stainless steel plate with engraved and filled letters reading "TRACK BRAKE". Track brakes shall also be energized when the Master Controller is in the "EMERGENCY BRAKE" position. Track brakes shall be controlled by Trainwire #14 so all track brakes throughout the train are energized, except that the slide detection and correction system applies the track brakes on a per-car basis, see Section 10.03, J.

10.07 FRICTION BRAKES (Continued)

A. Track Brakes (Continued)

2. Each car shall have a track brake contactor with suitable fuse in the coil circuit. Each truck set of brakes shall have a separate circuit breaker. The circuit breakers shall be mounted in the car circuit breaker panel in the operator's cab. The track brakes are powered from the car's low voltage power supply through circuit breakers P15 "TRUCK NO. 1 TRACK BRAKES" and P16 "TRUCK NO. 2 TRACK BRAKES".

3. The track brake suspension shall provide vertical adjustment to maintain rail clearance and shall have longitudinal and transverse stops with replaceable wear plates.

4. Track brakes shall be interchangeable with those on CTA's 3200 Series cars. The vertical suspension arrangement shall incorporate a rubber bushing at the bottom and shall be as shown on CTA Drawing R-1-1112, Page DR-21.

B. Friction Brakes

1. Four (4) spring-applied, hydraulic released disc brakes per car shall be provided. The discs shall be mounted on each gearbox assembly. The disc brake system and its details shall be reviewed by the Engineer.

2. Friction brakes shall be fail-safe, requiring power to release.

3. Friction brakes rates shall be as called for in Section 10.02, B, 4, from an entry speed of thirty miles per hour (30 mph).

4. An electric friction brake release circuit shall be provided to release the friction brakes while the Propulsion System on the car is cut out and the emergency relay is energized, see also Section 10.09, J.

5. A heavy duty manual friction brake release mechanism shall be provided to release each friction brake from both sides of the car. The mechanism shall permit quick release or re-application of the brake with a force of twenty-five pounds (25 lb) or less. The handles of the manual release mechanism shall be permanently colored bright yellow. A scheme similar to that on CTA's 3200 Series cars shall be provided to visually indicate whether a friction brake is cut in or cut out by looking at the manual release handle. The manual release mechanism and visual indicator shall be reviewed by the Engineer and demonstrated on the truck mock-up.

6. Heat generated during braking shall not cause damage to or shorten the life of seals and gaskets on the gearbox or caliper.

7. Discs shall be balanced to within 0.5-inch-ounce. Correction shall be made by means of removing metal from the outer periphery of the disc by grinding.

8. The brake caliper shall have an automatic slack adjuster to ensure proper operation without manual adjustment as the lining wears. Provisions shall be included to limit slack adjuster travel to prevent internal locking or jamming if both brake pad assemblies are missing.

9. The brake shall be mounted to the gearbox with at least four (4) bolts with safety wires. Resilient mounting shall be incorporated in the design of the operating mechanism to isolate it from the high levels of shock and vibration found in the gearbox axle assembly.

10. Each brake shall have switches or other means to indicate when the brake is applied or cut out. They shall be wired to operate the yellow indicating lights as described in Section 10.07, C, 5.

11. Friction pads shall be interchangeable mechanically and functionally with those on CTA's 3200 Series cars, unless otherwise agreed to by the Engineer. The caliper mounting bracket shall be cast iron or steel while the caliper body shall be cast aluminum.

12. The hydraulic power to release the friction brakes shall be developed by a continuously running pump powered from the car's low voltage system through circuit breaker P5. The pump motor shall be of the brushless dc type. The pressure shall be regulated by an electric solenoid valve within the unit. The unit shall incorporate filters to ensure that oil leaving the pump contains no foreign material that is injurious to the system. A high pressure filter shall be located between the pump output and the solenoid valve.

    This unit shall, if possible, be identical in mounting and shall have similarly located connection points to the unit used on CTA's 3200 Series cars and use as many of the same consumable parts as possible.

13. The system shall incorporate an isolation valve that shall shut off oil flow to each end of the car individually if a line is ruptured or broken. The valve shall be located adjacent to the hydraulic pump to protect the maximum length of line. The isolation valve shall connect to the hydraulic power unit through a quick disconnect, the same as used on CTA's 3200 Series cars.

14. The hydraulic fluid used in the brake systems shall be reviewed by the Engineer, as shall the cleanliness requirements of the oil in the system needed to maintain system operation. Fluid shall meet MIL-H-83282.

15. Provisions shall be provided at each caliper to bleed the lines following caliper or pump changes. Self-sealing disconnects may, with concurrence of the Engineer, be provided at each caliper to minimize the amount of bleeding needed. A filter shall be installed at each caliper inlet.

B. Friction Brakes (Continued)

16. Caliper and hydraulic power unit electrical connections shall be made through bayonet connectors the same as on CTA's 3200 Series cars, if at all possible.

17. Truck-carried hydraulic lines shall be routed away from the current collector area and carbody lines shall be routed as far from 600 Vdc electric cables and connectors as possible. Truck-carried hydraulic lines shall be jacketed with silicone rubber hose. Carbody lines shall be similarly jacketed in areas deemed necessary by the Engineer during the underfloor mock-up review.

18. A hydraulic pressure test point shall be provided at the hydraulic power unit to permit checking the output pressure. The pressure check attachment shall incorporate a hydraulic quick disconnect, the same as on CTA's 3200 Series cars.

19. A hydraulic quick disconnect shall be provided at each truck. The hydraulic truck quick disconnect shall be mounted on the carbody. Truck hydraulic quick disconnects shall be reviewed by the Engineer.

C. Brake Control

1. Friction brake rates shall be continuously variable as specified in Section 10.02 B, 4, and shall be controlled by the Propulsion System. The friction only brake rates with the Master Controller in the "MINIMUM SERVICE BRAKE" and "MAXIMUM SERVICE BRAKE" positions shall be measured from an entry speed of thirty miles per hour (30 mph).

2. Normal service stops shall be made with electric brake which shall maintain the rate to approximately three miles per hour (3 mph). As the electric brake fades, the friction brake shall be smoothly blended in to complete the stop and hold the train. The blending shall be controlled by the Propulsion System and the characteristics shall be PTU-adjustable. There shall be a "soft stop" feature to reduce jerk as the train stops. The exact settings shall be determined on the prototype cars.

3. In the event of a failure of electric brakes on one (1) truck, friction brakes shall operate as if electric brakes are fully functional.

4. In the event of a complete electric brake failure on a car, friction brakes shall automatically apply at the same rate as called for by the Master Controller and maintain the rate to a complete stop.

5. Operation of the friction brakes shall be indicated by the brake indicating lights on the Operator's Indicator Panel and in the three (3)-light assembly adjacent to the No. 3 and No. 4 side doors outside the car and on a per-car basis, via the CMN, on the TOTS in the active cab.

10.07 FRICTION BRAKES (Continued)

C. Brake Control (Continued)

6. The lights shall light when any Master Controller in a train is unlocked. The lights outside a car shall light when any brake on that car is applied or manually cut out. If a brake is cut out, the lights outside the car shall remain lit as long as a Master Controller is unlocked.

7. The light on the Operator's Indicator Panel shall light when any brake on a train is applied, but shall not light when a brake is manually cut out.

D. Emergency Relay Circuit

1. An emergency relay loop circuit shall be provided in each two-car unit. An emergency brake application shall take place in the event of any opening of the emergency relay circuit such as:

- Train separation.
- Opening of track trip switch.
- Opening of Passengers' or Operator's Emergency Switch.
- Placing Master Controller handle in "EMERGENCY BRAKE" position.
- Opening due to broken wires.

2. An opening of the emergency relay circuit shall cut off traction power and cause an emergency brake application consisting of maximum full service electric brake rate plus 2.5 mphps friction brake rate. If full electric brake is not available, for any reason, the friction brake rate will be the maximum full service rate.

3. There shall be a Passengers' Emergency Switch with spring return reviewed by the Engineer located in each car at the No. 2 end in a location reviewed by the Engineer. The operating handle shall be equipped with a CTA standard red ball, CTA Drawing No. E-1-503, Page DR-4.

4. There shall be an Operator's Emergency Switch with spring return reviewed by the Engineer located in each operator's cab in a location reviewed by the Engineer and demonstrated in the cab mock-up. The operating cord of transparent red vinyl with wire center shall be equipped with a CTA standard red ball, CTA Drawing No. E-1-503, Page DR-4.

10.08

MASTER CONTROLLER

A. General

1. A Master Controller shall be provided in each operator's cab. The Master Controller shall be supplied as a single integrated unit. Connection to car wiring shall utilize bayonet connector(s), as specified Section 9.02, J.

2. The Master Controller shall interface with the Propulsion Control Network (PCN) as specified in Section 15.07, and shall provide train control commands controlling train tractive effort. Means shall be provided to prevent more than one (1) Master Controller to control the train simultaneously.

3. The top of the Master Controller shall be plainly and permanently marked to indicate the positions of the operating handle. The "MAXIMUM SERVICE BRAKE" position shall be indicated with yellow. The method and materials used shall be reviewed by the Engineer.

4. If the Master Controller has a removable top cover or mask, it shall be possible to remove the mask without removing any cab trim or equipment. It shall also be designed to prevent any object from entering and jamming the Master Controller.

5. If escutcheon plates are used, they shall be 0.125-inch thick stainless steel with engraved and filled numbers and letters. They shall be free of any sharp edges.

6. Any objects, which may enter the operating handle or reverser key slots, shall safely fall clear of the operating mechanism without jamming the Master Controller.

7. The Master Controller and its housing shall be reviewed by the Engineer and demonstrated in the cab mock-up.

B. Operating Handle

1. The Master Controller shall control both acceleration and braking with a single handle. The operating handle shall be equipped with a "DEAD MAN" feature which will shut off power and apply a maximum service brake rate when released in any operating position except "EMERGENCY". After a "DEAD MAN" brake application or an emergency brake application, the controller handle must be moved to the "MAXIMUM SERVICE BRAKE" position to reset the brakes and restore normal operation.

B. Operating Handle (Continued)

2. The Master Controller operating handle shall be designed and positioned for left-hand or right-hand operation with equal comfort. The operating handle shall move forward and rearward. Power positions shall be activated by a forward motion of the controller operating handle, with progressively increasing acceleration and speed. The “COAST” position shall be in the middle between the “POWER” and ”BRAKE” positions. Moving the handle rearward from the middle position shall command braking with progressively increasing rates. In the rear most position the emergency brake shall be applied.

3. The “DEAD MAN” feature shall be of a twist-type. The twist feature shall not require any awkward or uncomfortable position or motion of the hand when initially grasping the handle. The “DEAD MAN” feature shall be highly resistant to deliberate attempts to defeat its operation.

4. The operating handle design shall minimize strain and fatigue on the operator. The spring force required by detents, see Section 10.08, D, 3, handle length, handle travel between detents, and other operational characteristics shall be demonstrated in the cab mock-up.

C. Reverser Mechanism and Key

1. The reverser mechanism shall be operated by CTA’s standard reverser key, Westinghouse Air Brake Company’s No. A529107, or General Electric 41B556018P1, and shall have three (3) positions, marked “REVERSE”, “OFF”, and “FORWARD”. “FORWARD” shall be the position closest to the windshield. If the operating handle is in the “OFF” position and the Reverser Key is in “OFF”, the Master Controller will be locked up and the key may be removed.

2. It shall not be possible to remove the reverser key unless the Master Controller is locked up.

3. One (1) key shall be provided for each Master Controller and shipped separately to the Engineer. Reverser keys shall be investment cast stainless steel.

4. The reverser key slot shall be of such design that it shall not be possible for a key to fall into the controller.

5. The reverser mechanism shall be easy to operate and shall not bind.

10.08 MASTER CONTROLLER (Continued)

D. Operating Mechanism

1. The Master Controller operating handle shall have seven (7) positions marked from forward (closest to the windshield) to rear: "MAXIMUM POWER", "MINIMUM POWER", "COAST", "MINIMUM SERVICE BRAKE", "MAXIMUM SERVICE BRAKE", "EMERGENCY BRAKE", and "OFF".

2. The Master Controller shall provide infinitely variable control of initial acceleration rate and tractive effort between the "MINIMUM POWER" and "MAXIMUM POWER" positions and braking rate and braking effort between the Minimum and Full Service Brake positions. The Master Controller shall produce acceleration and braking effort linearly proportional to the operating handle position.

3. Detents shall be provided in the "OFF", "EMERGENCY BRAKE", and "COAST" positions. The ends of "MAXIMUM POWER", "EMERGENCY BRAKE", and "OFF" positions shall be limited by mechanical stops.

4. It shall be necessary to depress a button on the controller to permit moving the operating handle into the "OFF" position. The button shall have a label attached to the controller reading "OFF POSITION RELEASE". The button need not be flush with the top surface of the Controller and cannot be in a position that obstructs the use of the Controller handle by a right- or left-handed operator.

E. Switches and Encoders

1. The Master Controller shall use cam operated switches of modular construction to carry out its digital controlling functions and shall be reviewed by the Engineer.

2. Analog functions shall be generated by directly-driven encoder(s).

10.09 BLUE LIGHT TROUBLE INDICATOR SYSTEM

A. A Blue Light System reviewed by Engineer designed to indicate failures in the Propulsion System and Auxiliary Power Supply System in any car of the train shall be provided. The blue lights shall be located on the Operator's Indicator Panel and on the outside of the car in the four (4) light assemblies adjacent to the No. 3 and No. 4 side doors. The blue lights on the operator's indicator panel shall be lit only when the Master Controller is unlocked. The blue lights outside the affected car shall remain lit, having once come on, until reset by repair personnel, except as specified.

B. An audible alarm bell shall be located in each operator's cab and shall sound when the blue light on the indicator panel is lit. The location and type of bell shall be reviewed by the Engineer and demonstrated in the cab mock-up.

10.09 BLUE LIGHT TROUBLE INDICATOR SYSTEM (Continued)

C. The Control Reset Push Button switch shall be located on the Operator's Indicator Panel, as specified in Section 9.05, E, 7. It shall be functional only when the Master Controller is in the "EMERGENCY BRAKE" position.

D. The outside blue lights shall be powered from the car's low voltage power supply through P30 "SIGNAL LIGHTS". The cab blue light shall be powered from P3 "POWER CONTROL".

E. An event display panel as defined in Section 10.10, and reviewed by the Engineer, shall be provided on each car, located in the Propulsion System car control unit. It shall be designed to distinguish which of the inputs caused the blue light indication. The panel shall incorporate a switch which when operated shall cancel the outside blue light and reset the displayed event.

F. In the event of a Propulsion System or Auxiliary Power Supply System fault, the blue light on the Operator's Indicator Panel shall light, the audible alarm shall sound, the outside blue lights on the car with the failed equipment shall light and there shall be an indication of the car number with the failed equipment displayed on the TOTS. Operation of the Control Reset Push Button in the active cab with the Master Controller in the "EMERGENCY BRAKE" position shall acknowledge the fault, turn off the audible alarm, turn off the cab blue light and turn off the outside blue lights (unless the car is cut-out). The TOTS then shall reflect the current status.

G. The Contractor shall develop a list of the Propulsion System fault events triggering blue light indications. Only major failures or defects in the Propulsion System that restrict the operation of the Propulsion System shall cause a blue light. Faults other than those reviewed and agreed to by the Engineer shall not cause blue light indications. Under no circumstances shall a wheel spin or slide be indicated as a failure on the Blue Light System.

H. The Contractor shall develop reset and fault isolation actions, as well as hardware and software provisions for their implementation. The Contractor shall impose a limit to the number of resets within a given time period.

I. Once the allowable number of resets has been reached and the Master Controller has not been locked up during the time between resets, it shall not be possible to reset again and the failed equipment shall be automatically cut out. The cab blue light shall remain on and the audible alarm shall continue to sound until the failed equipment is cut out. The actions taken shall be displayed on the TOTS. Once the failed equipment is cut out, the cab blue light and the audible alarm shall be shut off, while the outside blue lights shall remain lit, being turned off only by repair personnel.

10.09 BLUE LIGHT TROUBLE INDICATOR SYSTEM (Continued)

J. A rotary control switch as specified in Section 9.05, F, 3, shall be also provided for manual cut out of the car propulsion-braking circuits and control. This switch shall be located in the car circuit breaker panel. A set of contacts on the switch shall electrically release the friction brakes as long as the emergency relay is energized and the car is turned on.

The switch shall have two (2) positions identified with permanent labels as follows from left to right:

1. "CUT IN".

2. "CUT OUT".

The "CUT OUT" position of the switch shall be displayed on the TOTS.

If the switch is cut out after a trouble indication, it shall provide a permanent outside blue light; if it is cut out without a trouble indication, the outside blue lights will go out if the switch is cut in.

10.10 DIAGNOSTICS

A. The Propulsion System shall include a built-in diagnostic package that shall monitor and report on the operation of the system. This diagnostic package shall require no special skill or knowledge to operate and understand. All aspects of this package shall be reviewed by the Engineer and changes that are found to be needed during the prototype car tests and warranty period shall be made at no cost to CTA.

The diagnostic package shall include a feature that creates a series of data files that store all the real time monitored elements such as voltages and currents, contactor positions, input and output signals, and command and response signals as well as date, time and car number. The files shall be recorded at least once every fifty milliseconds (50 msec), for a period of at least three seconds (3 sec) before, and two seconds (2 sec) after each logged event. At least twenty (20) sets of files, snapshots, shall be saved before overwriting the first one. Every effort shall be made to maximize the number of snapshots that can be stored.

10.10 DIAGNOSTICS (Continued)

A. (Continued)

1. The system shall have an event display to assist field personnel in identifying the problem devices, card, or sub-system within the system.

   The event display shall be an alphanumeric or numeric display, not individual LEDs, with separate scrolling and reset buttons and an indication of microprocessor operation in the form of a blinking LED (heartbeat). A display test function shall be part of the diagnostics accessed through the scroll buttons. The separate reset button shall reset the event display and reset the system inhibits/lockouts.

   The display elements shall be as large as possible for easy reading. An explanation of the display readings shall be provided adjacent to the display in a permanent form, reviewed by the Engineer.

   The event codes shall be no more than four (4) characters.

   The event display and its functioning shall be specifically reviewed by the Engineer.

2. The onboard unit shall be able to display at least 999 events recorded by the microprocessor since a previous action.

B. Events recorded by the microprocessor shall be divided into restrictive and non-restrictive classifications.

1. Restrictive events shall result in inhibiting appropriate functions following a set number of occurrences and shall be communicated to the maintenance screens of the TOTS via the CMN.

2. Non-restrictive events shall only be recorded and shall not inhibit control operation.

The classification of all events and inhibit quantities shall be reviewed by the Engineer.

10.10 DIAGNOSTICS (Continued)

C. The Contractor shall furnish rugged Portable Test Units (PTUs) as specified in Section 17.04, to access the microprocessor controls beyond the onboard diagnostics. The PTU shall perform the following functions:

1. Fault event display and reset.

2. System inhibit/lockout reset.

3. Manual test of the system and devices.

4. Data memory display of system operation both before and after fault shutdown of the system (snapshots), see Section 10.10, A. In addition, it shall be possible to create snapshots (real time recording of system operation) by setting snapshot parameter levels to trigger a memory function of system operation. These recordings shall be of at least twenty seconds (20 sec) duration. This function shall be reviewed by the Engineer.

5. Real-time monitoring and recording of Propulsion System performance and operation.

6. Download of data from the car to PTU memory/storage for later analysis.

7. Display and adjust Propulsion System performance parameters, fault event parameters and fault lockout parameters that are adjustable, including wheel diameter value used for automatic calibration of the car speed.

8. Download software from PTU to Propulsion System.

9. Display car number, mileage, date and time.

D. Appropriate levels of security shall be incorporated to prevent unauthorized access to and erasure of various functions and information. The security levels and their contents and the passwords used shall be reviewed by the Engineer.

E. The Contractor shall provide bench test equipment for use in the main shop to test, adjust and repair individual boards and the entire microprocessor control unit. These shop units shall be complete as specified in Section 9.11.

The Contractor shall furnish instructions/documentation, including Maintenance and Parts Manuals, for all test equipment, as specified in Section 9.11.

F. The PTUs shall plug into test receptacles located in the car control unit adjacent to the display panel and in the operator's cab. The cab receptacle shall not be combined with that for the Auxiliary Power Supply System. The receptacles shall be as defined in Section 9.19. These requirements shall be demonstrated in the cab mock-up.