Conversion of Overhead Contact Systems
Poles to Pantographs

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INTRODUCTION

The Toronto Transit commission (TTC) has a total streetcar track mileage of 81 km [51 miles], over 100 complex intersections and has operated streetcars with trolley pole current collectors since it began operating in 1921. Prior Companies had used pole operation since the inception of electric streetcar in August of 1892. The more recent PCC cars used trolley poles and the overhead remained compatible for trolley poles. The replacement vehicles to the PCC car, known as the Canadian Light Rail Vehicle (CLRV) manufactured by Hawker-Siddeley at Thunder Bay Ontario, were equipped with trolley pole current collectors of the same type and style as the PCC cars, being a 14 foot trolley pole with a one and one-half inch diameter pole butt at the end, an Ohio Brass Form-11 Light Weight two spring trolley base and Type-J Trolley Harp with carbon shoe.

Two types of cars were purchased, double truck single cars CLRV (*Fig. 1*) and three truck, two section articulated cars ALRV (*Fig. 2*). The articulated version was 23.164m [76.0 ft] ft long while the non-articulated version was 15,226m [49.95 ft] long with truck centers at 25 ft. The cars are single end and turn direction by accessing loops at terminal points.

TTC placed an initial order for 200 new vehicles from the Ontario Transit Development Corporation later named Urban Transit Development Corporation (UTDC) and with Hawker-Siddeley, embarked on a project to design a new streetcar in 1972. In August of 1973, TTC placed an initial order for 200 new vehicles from OTDC, ten prototypes of which would be designed and built by a manufacturer in Switzerland called Schweizerische Industrie Gesellschaftbefore (SIG).The order for 10 Swiss CLRV models was cut back to six in the late 1970's to provide parts needed to build an experimental articulated version of the design but only one articulated prototype was built. In the meantime, the new SIG cars started to arrive in 1977 and 1978 with the UTDC cars starting in 1979. Revenue service started in September of that year. In 1988 the first of 52 ALRV's was entered into revenue service. By 2009 they began reaching the end of their useful life and the City of Toronto and the Toronto Transit Commission began the process of replacement.

The power draw requirements for both types of vehicles were nearly the same being 272 kw (453 amperes) and 260 kw (433 amperes) for the CLRV and ARLV respectively. The collector shoes could handle this current value adequately without overheating or undue carbon wear and the trolley poles were able to negotiate the existing overhead contact system (OCS) without issue.

EXISTING OVERHEAD SYSTEM

Overhead System Type

The existing OCS that was in place worked extremely well and the Commission wanted to retain it but determined it was not adaptable for pantograph operation. The system was a traditional direct suspension double insulated system using 1/4” and 5/16” span wire made up with preformed end fittings, fiberglass rod insulators used for span wire insulation at poles, with AGC span wire hanger or cap and cone hangers with 12 inch HS clamp ears to hold the trolley wire, No-Bo section insulators, Type SH trolley frogs and crossover pans and a 2/0 grooved alloy 80 bronze trolley wire. It was a classic overhead contact system that functioned very well with trolley pole current collectors, and was very easy to maintain.

Fig. 1

Fig. 2

The Spadina line, which was completely rebuilt by 1997, used different OCS hardware and design criteria than the core system. Suspension of contact wire was with stitch or delta configuration using a line insulator with a pulley, synthetic rope and two contact wire clamps for tangent construction.

Curves used pullovers with a long clamp ear referred to as a curve rail having a clamp that bolted to the rail in two places with greater spacing. Attached in the center of this was a boss for screwing a suspension piece on. This was bolted onto the clamp for pulling it into alignment. Fiberglass rod insulators were attached to each side of the suspension piece to add insulation as span wire was steel.

The pullover accommodated large angles for enhanced pullover spacing and the curve rail smoothed out the abrupt angle so the shoe could pass through it. Multiple pulloffs were eliminated by this method and the curves of grand unions and wyes became more aesthetically pleasing as a result.

The Spadina line also used OCS support poles that used ornamentation, architectural enhancements and were joint use with city streetlights.

Section Insulators

One OCS feature unique to Toronto was the use of No-Bo section insulators with a large diode feeding the neutral section (*Fig. 11*). TTC standards dictate that section insulators are to be non-bridging for safety and the older No-Bo style section insulator provided this feature. Operational rules required the streetcar operators to coast through the section insulators so arcing would not occur and minimize insulator burning. The spacing of section insulators at 20 feet apart prevented regenerative section bridging across a single section insulator and this arrangement was introduced with the operation of the CLRV’s due to their regeneration capability.

Under normal operation, the streetcar passes through the first section insulator onto the neutral zone but receives power from the next power section through a large capacity diode. The streetcar then passes through the second section insulator into the next power section. In the event the power section in the adjacent section was dead, the car would pass through the first section insulator and as it regenerated from braking, the diode blocked the current from passing into the dead section and prevented it from becoming alive.

OCS Support Poles and Bracket Arms

The Commission used tubular three section steel poles of varying sizes and heights which were directly embedded into the earth with a concrete foundation around the embedded section. As these corroded over time, replacement was necessary and a decision was made to standardize on one type of pole, which was an extra heavy steel pipe of constant diameter. Three sizes were used, an 8 inch, a 10 inch and 12 inch pipe with lengths varying to that needed for each particular installation. The standard poles are direct embedded in a concrete foundation. Anchor base poles are utilized in certain locations.

The Commission has many locations where bracket arms are used to support the trolley wire. They are typically 2 inch standard weight pipe, galvanized and attached to the pole with a pipe insulator and pole clamp. The arm uses a guy wire to support it. Some areas of the system required non-standard bracket arms for streetscape enhancement and interesting styles were used on St. Clair and Spadina Avenues.

Feeder Cables

Feeder cables are typically 1000 kcmil copper insulated cable strung aerially on poles or in underground conduits. Feeder taps connected to the aerial cables are run to the trolley wire and connected to it with a bronze feeder ear. Underground taps rise in conduit, outside the OCS pole and run to the trolley in the same manner as the aerial taps. Cables are attached to poles with fiberglass standoff insulators attached to the pole with galvanized steel pole bands.

Span Wires

Span wires consist of 5/16" seven strand galvanized steel guy wire for suspensions and pulloffs, 3/8" seven strand galvanized steel guy wire for back guys and heavy loads and 1/4" seven strand galvanized steel guy wire for steadying bracket arms. Typically at poles, a 5 ft. fiberglass rod strain insulator attached to the span wire to provide secondary insulation as the trolley wire is attached to a line insulator which attaches to the span wire. At the bracket arms, insulators were placed in the span wire steady spans at the pipe. The Commission maintains double insulation at a minimum.

Originally, span wires were terminated by serving the strands around itself but this method has been replaced with Preformed End Fittings.

NEW STREETCARS

When it was decided by the Commission that new streetcars were needed due to the CLRV and ALRV streetcars would be nearing the end of their useful life, the Commission began searching for a manufacturer to build the streetcars. In 2009, it was announced that the Bombardier Flexity Outlook would be the replacement vehicle. Testing began in 2013 and revenue service started on August 31, 2014 on the 510 Spadina route.

These cars are five section articulated vehicles 100 ft long with low floor easy access. They are single ended and use track intersections and loops to turn around. *Figures 3 and 4* show the operation of the new car with a trolley pole and a pantograph.

Fig. 3

Fig. 4

PRELIMINARY ENGINEERING

Current Collectors

One of the primary concerns of the Overhead Section was the compatability of the existing overhead contact system with the new vehicle's pantograph current collector. As TTC had no experience with pantograph operation, they contacted several transit agencies and conducted meetings to find out their experiences with pantograph operations and pole to pantograph conversions. Commission line supervisors traveled to Philadelphia to meet with their counterparts and were able to receive valuable information on pantograph operation or trolley pole to pantograph conversion. Commission engineers also contacted and met with consultants who had pole/pantograph conversion experience.

Interestingly, the department did not want to run with pantographs as the entire overhead network would have to be rebuilt but the new streetcars had significant current draw of 100% more current, well above that of the existing streetcars. The department engineers explored various options for current collectors including articulated trolley shoes and a longer carbon shoe and holder (*Fig. 5 and 6*)

Fig. 5

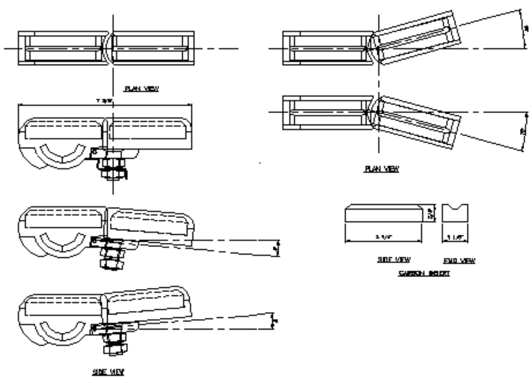

Fig. 6

Extensive testing was undertaken with an ALRV that was altered to draw the same current through the trolley pole as the Flexity streetcar would draw using the longer TTC shoe as the current collector shown in *Fig. 5*. It was surmised that the longer carbon would be able to handle the added current draw of the new streetcars. To negotiate trolley frogs, the side walls of the shoe were kept the same length as the standard shoe but the shoe body and carbon were lengthened. The long shoe worked extremely well tracking through trolley frogs, crossover pans and curve pullover ears but with sustained currents of over 1,000 amperes flowing, it could not resist the heating affects and at one point during the testing, the shoe became so hot that it glowed red.

It was evident from this testing that trolley poles with a modified carbon shoe for additional current draw were insufficient and pantograph current collectors had to be adopted. From this determination, preparations were made to convert the overhead system.

NEW OVERHEAD SYSTEM

Preliminary Engineering

The new streetcars were to be phased in and delivered over a period of time as the entire order could not be delivered at once. Therefore, the overhead system would have to be able to allow operation of poles and pantographs for an extended period of time.

Commission engineers reviewed the information provided to them from the other agencies and decided to have consultant assistance with the process of overhead conversion due to the design effort required. They interviewed various firms and manufacturers and formed an approach to see which consultants could assist them. They also wanted to ascertain the compatibility of different OCS manufacturer’s components for use on the system and contacted several companies.

The Commission placed a tender for overhead design services and chose three firms that would be assigned tasks, SDJ Electra, Gannett Fleming, and HNTB Corporation. The Commission also approached three OCS suppliers for design assistance and material components to be used in the consultants designs. Kummler + Matter and Impulse NC were chosen as the third manufacturer did not want to assist with the design effort.

As part of the initial design effort, HNTB was asked to prepare a report for pantograph operation in the Eglinton Tunnel, part of the Metrolinx new streetcar project. There were extremely tight clearances and low trolley wire heights and the Commission engineers needed information on the various type of OCS that could be used in such a situation. In HNTB’s report, optional overhead systems were presented and the advantages and disadvantages highlighted. The optimal system was rigid conductor rail as current collection for the Metrolinx system was all pantograph and separate from the core TTC system.

A fundamental difference with the Metrolinx system was that it had standard gage track of 4.71 feet rather that the TTC standard of 1.4953 m [4.906 feet]. This track gage difference unfortunately made assurance that the two systems could never be easily linked.

Engineering Assignments

The Commission engineers have historically designed their overhead system and any changes, additions or new construction have been and still are undertaken by the Commission’s Overhead Section. The Commission also does their own overhead construction and maintenance as their crews are highly skilled and trained for trolley line work. One of the highlights of their abilities is to work the lines alive and do work with service running. Their mantra is to keep the service running under any and all situations only if it can be done safely.

The engineering staff and the line maintenance and construction crews work closely together and commiserate on designs, hardware, service situations to ensure that what is specified in the designs is what will be able to be constructed easily, efficiently and economically. In short, the engineering and construction forces are partnered for the best OCS possible.

Engineering the OCS

The first two designs undertaken and constructed were the Fleet loop and the Earlscourt Loop with HNTB Corporation doing the former and SDJ/ELCON Associates doing the latter. Earlscourt Loop was designed and built with ImpulseNC hardware and Fleet Loop with Kummler + Matter (K+M) hardware. During the construction, the line crews evaluated the different types of overhead hardware from the two manufacturers supplying the equipment and made decisions on what material worked the best for them. They considered ease of construction, ability to make adjustments, weight of the components, appearance of the OCS and operation through the completed overhead by streetcars. Various components from K+M and ImpulseNC were chosen including some standard TTC designed hardware and a master material list (MML) was established with many of the specialty hardware from K+M.

The MML had each component listed by description, vendor part number, and TTC listing number. A part number 88 was for Phillystran 11 mm Diameter Span Rope, part number 1 was for 4/0 alloy 80 grooved bronze trolley wire, part number 73 was for a turnbuckle eye & eye, and so forth. This allowed a consistency between various loop, yard and intersection designs, ensured that the different designers would call out a particular item with the same part number, and identify it in their material list in the same manner as the Commission engineering staff was listing it. HNTB presented this method to the Commission engineers during the first Fleet Loop design and it became the standard for all designs from thereon.

HNTB also assisted the Commission engineers with establishing new standards of design criteria and construction for joint operation of poles and pantographs. The Commission had in place established standards and methods for design but they were based on exclusive trolley pole operation and as HNTB had significant experience with conversion, operation and engineering streetcar systems, a review of design and construction methods was undertaken.

The Commission had developed ways to measure and layout the overhead on curves for trolley pole operation and discussions with HNTB about this evolved into an alternative approach than was currently being used which provided an easier pulloff offset location with pantograph operation.

In laying out curves, crews located the trolley frog, pullovers and offsets according to the design drawings prepared by the engineering staff. The frogs are located first and then all pullovers determined from the frog as this is the reference point. Trolley frogs are located from a measurement at the end of the track casting of point mate street switches to the back of the frog hanger and this has not changed.

When Commission engineers prepare an OCS design drawing, they include the track rails and have a detailed track switch casting in the track to exact scale. For intersection drawings, a table is made and placed in the drawing that provides the frog location measurement, i.e. end of casting (E.O.C.) to back of frog hanger. Each track switch is provided a number in the drawing so it can be referenced in the table. Frogs are typically located directly over the center of the track but if a switch is in a curve, the frog may have to be offset from the track centerline to accommodate proper pole tracking and each location is determined on a case by case basis.

Frogs are not cut into the trolley wire but the wires run through the frogs and approach tips are used. Prior to the start of new construction, the existing turnout 2/0 trolley wire was terminated at the frog hanger and either a frog guy was used or the suspension spans attached to the frog to hold it in place. It was recommended by HNTB that any new construction at trolley frogs have the turnout wire run completely through the frog to a point beyond the track rail of 0.46 m [1.50 ft] where the deadend would be attached to the span rope.

The reasoning for this is that when total pantograph operation is in place, the trolley frogs can be removed from the trolley wire and replaced with a cross contact wire clamp and jumper cable without having to splice trolley wires or adding additional deadends as they will already be in place.

Offsets for trolley wire on curves for all pole operation were previously measured from the inside curve rail towards the center of track during this period of operation. This was changed for joint operation to having all offset measurements taken from the center of track towards the inside of the curve. Staggers on tangent track were measured from the center of track towards the rail and continue to be done in this manner. Since the pantograph is directly over the center of a truck, and its centerline coincides with the track centerline, it was logical to measure offsets and staggers from the centerline. Spacing of the pullovers around a curve starts at the back of the frog hanger and goes in the direction of traffic to the end of the curve.

With all pole operation, trolley wire offsets from the center of the track were dictated by the radius of the track curve so the trolley pole would have its shoe tangential to the pullover. Commission engineers determined the correct offset with formulas and graphics used in the design. The offset for a 15.2 m [50 feet] with the CLRV's is 610 mm [24 inches] and provides proper pole tracking through a curve. The dimensions of the pantograph on the new Flexity streetcars are such that the wire on a 15 m curve would place it at the edge of the horn at the pullover and on the horn between pullovers. This was an unsafe condition and the Commission engineers designed a compromising offset that would work for both types of current collectors. They developed a range of travel from the center of the track that varied from 229 mm to 300 mm. As long as the trolley wire was in this location on the curve, poles could track without dewirement and the pantograph could traverse the curve without fear of the trolley wire leaving the horn. On tangent track, the wire was staggered by 80 mm [3.14 inches].

Each drawing has pulloff spacing indicated so the line crews can layout the curve on the track itself and locate the overhead wire pulloffs directly over the mark on the street. If there is a bust in the measurements for some reason, the crews can alter the pulloff spacing in their marks on the street to ensure proper location of pulloffs before they start constructing. This rarely occurs as the drawings are to scale.

All overhead designs are superimposed on the official track geometry design drawings which are to scale and exactly what is laid out and constructed in the street so the only way to misalign the OCS would be through a typographical error in the OCS drawings. As all Commission designs are double checked for accuracy, typos are rare.

The OCS layout drawings included the height of the span wire on the pole, the tension in the span wire at the worst loading conditions, the resultant rake direction and the bending moment. All of this information became somewhat confusing for the construction crews so on later design drawings, only the span wire heights and the resultant rake direction arrow was shown on the drawing.

The New OCS System

A standard overhead system was established and used for the design and construction of the new OCS. The former direct suspension system was replaced with an elastic suspension system consisting of an inclined stitch (delta) supporting the contact wire at spans and bracket arms on tangent, and flying pullovers on curves where they would float creating a soft suspension. Under bridges, a rolling suspension was used and in the Queen's Quay to Union Station tunnel, elastic arm suspension was employed. Contact wire size was increased for electrical capacity and wear characteristics. Since the system was to be dual operation for an extended period of time, trolley frogs and crossing pans continued to be used.

Span Wire

The Commission standard span wire was changed from 5/16" 7 strand galvanized steel guy strand to non-conducting span rope from Phillystran®. The size and type chosen was HTPG 11200 with a breaking strength of 50 kN [11,200 ponds] and a diameter of 11 mm [0.42 inches]. This material has an Aramid fiber core with an extruded polyethylene jacket and is completely non-conducting and of high dielectric strength. It is secured at terminations with either preformed end fittings or NicoPress sleeves. In both cases a thimble is used to form the loop and prevent abrasion. The preform has a made up length of 1294.4 mm [51 inches] so in tight clearance locations the use of four NicoPress sleeves is 254 mm [10 inches] in length. In the event the sleeves are close to a grounded structure, they are taped for additional insulation.

This material has been a complete replacement for all span wire used in the OCS with the exception of back guys which are still 3/8" steel guy wire. An interesting feature of span rope is its very light weight and ability to shed ice easily as it does not adhere to the rope jacket.

The line crews found favor with it as it is non-conducting and can be run over energized trolley wires without fear of short circuits, electric shocks or burn downs. Its light weight made it easier to handle and it didn't have "coil memory" that would cause it to spring off the wire reel as steel span wire did.

Contact Wire

The contact wire was changed from 2/0 alloy 80 trolley wire to 4/0 alloy 80 trolley wire, all grooved. Cadmium bronze was initially used but this was changed to magnesium copper with 85% conductivity due to concerns of Cadmium being carcinogenic. The

Commission determined decades ago that bronze trolley wire was less susceptible to accelerated wear and fatigue cracking than hard drawn copper trolley wire and has continued its use. It can be pre-stressed to limit creep and in an environment where temperatures can range well below zero from -40°C to 49°C [-40°F to 104°F], this wire works very well and is superior to copper.

Contact wire on straight runs is tensioned to full value and when on tight curves such as intersections and loops, it is half tensioned. With the temperature ranging from -40° C to +40° C, the mean temperature chosen was 16° C [60° F] and the full tension was 890.8 DaN [2,002 lbs] and at half tension 485.0 DaN [1,090 lbs]. The Commission refers to the reduced tension as half tension but in reality, it is a reduction of full tension and is shown on Table 1.

Contact Wire Tension Chart

Temp °C	Half Tension (daN)	Full Tension (daN)
-40	1502.7	4557
-18	1050.2	1562.8
16	485.0	1090.0
29	352.4	644.8
40	287.0	498.0

Table 1

Suspension Assemblies

Tangent Suspension

The contact wire is suspended from the span rope or bracket arm with different suspension hardware. On tangents, a stitch assembly is used consisting of a line insulator, a pulley through which a 3 meter [9.84 feet] long Aramid stitch rope with terminations passes. It is attached to trolley wire clamps that have a bracket which is adjustable 180 degrees to the horizontal of the contact wire. This allows the stitch to be offset for stagger creating an inclination where the bracket can be adjusted so that the trolley wire clamp sits vertically on the wire. This is important as it prevents the trolley pole collector shoe from scrubbing against the side of the clamp.

Inclined pendulum hangers are also used but to a limited degree. These can be short or long but also provide an elastic suspension as the contact wire is free to lift up unencumbered as pantographs or trolley poles pass by preventing accelerated wear of the contact wire.

Rigid direct suspension is also used but to a limited degree. This is where the line insulator is clamped to the span rope with a clamp ear to which the contact wire is held. There is no flexibility in the suspension and the contact wire can be worn at this point as a hard spot develops.

Curve Suspension

Curve suspension uses flying pullovers that have a curve line insulator with a suspension eye to which is attached a 4 mm diameter steel hanger wire with two loops. These have a non-conducting J thimble inserted in the loop to prevent abrasion and add a measure of insulation. A curved pullover rod is placed in the free end of the hanger wire and has a clamp ear attached to its curved threaded end (*Figure 7*).

The advantage of these over the old cap and cone hangers is that the curve pullover assembly is clamped to the span wire without cutting into the wire. This allows greater flexibility in adjustment and faster construction time. The pullovers are either single rod or double rod where angles between 2-8 degrees use one rod. For angles over 8 degrees, two rods are used, spaced 710 mm [27.95 inches] apart at the contact wire. The rod is curved and when suspended in the curve, it affords good clearance to the pantograph when lifted up from the pressure of the pantograph even during elevated temperatures when the contact wire has low tension.

A long clamp ear referred to as a curve rail is screwed onto the end of the pullover rod for securing the contact wire. The rail is 600 mm [23.6 inches] long and bends to a smooth curve allowing trolley poles to traverse them without banging.

Fig. 7

Trolley Frogs and Crossover Pans

Trolley frogs will be used during the transition period of pole/pantograph operation. Frogs are standard SR type with renewable tips and are 10 degrees. They are placed in the wire directly over the track centerline at a particular location from the end of the point mate casting where the trolley pole shoe becomes 10 degrees to the tangent wire as the streetcar takes the curve. This is done for both taking and trailing operations.

The main line contact wire runs straight through and the frog is clamped to it. The turnout wire runs through the frog beyond the frog where a deadend clamp is attached outside of the tracks by 0.46 m [1.50 feet] outside of the running rail. With the old system, the turnout contact wire was deadended at the frog. Running the turnout wire beyond the frog is for future all pantograph operation when the frogs will be dropped out and the deadend wire will become a turnout crossing wire (*Figure 8*). A cross contact clamp will be installed along with an equalizing jumper.

Operation through the frogs with pantographs requires gliders to prevent the pantograph carbons from striking the frog hanger. Gliders are attached to the frog after it is installed. The glider allows poles to pass through with clearance. The entering end of the gliders have a bar (anti-trapping guard) closing them to prevent a dewired trolley pole from becoming tangled into the gap between the glider and the frog body (*Figure 9*).

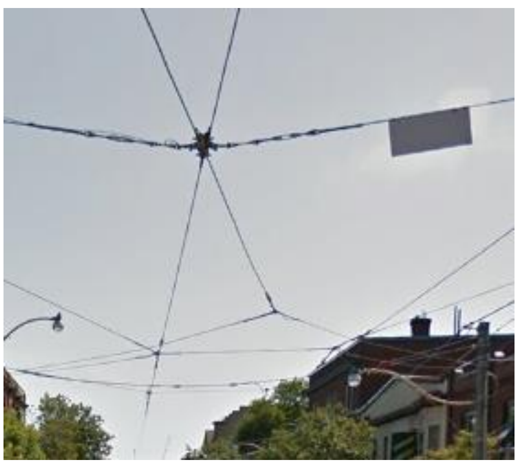

Fig. 8

Crossover pans accommodate poles and pantographs and the original design called for utilizing the existing SR crossovers with a glider made of 4/0 bronze trolley wire. It was configured in such a way that when installed on an adjustable crossover, the glider could rotate to the final angle. An adaptation to this was made by K+M and is shown in (*Figure 10)*. Ninety degree crossings used a completely new pan that did not have gliders but was sloped so that pantographs could pass through.

Fig. 9

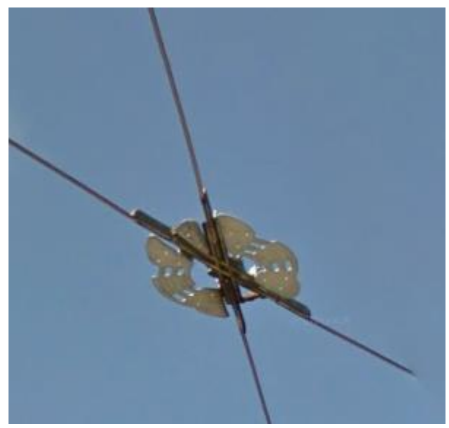

Fig. 10

Section Insulators

The Commission used the standard No-Bo section insulator for PCC and CLRV operation in a special arrangement. With the advent of CLRV operation, there was concern about accidently energizing a dead power section if a CLRV regenerated into the dead section with line crews working on the line. To prevent this type of accident, Commission electrical engineers devised a unique method of sectionalizing the line at power section boundaries.

This method used two section insulators spaced 6.09 meters [20 feet] apart. As the piece of contact wire between the two section insulators was normally dead with no feed, the engineers devised a method of feeding this “dead zone” with a diode. A 2,500 volt, 1,400 amp disk diode was placed in an assembly with a heat sync on the second section insulator and the feed coming from the power section the vehicle would be travelling into. The dead trolley wire was normally energized through the diode until the power section feeding it went dead. When this occurred, the middle piece of trolley wire also went dead.

The diode prevented current from passing from the middle wire during regeneration into the dead power section by the inherent nature of the diode. The 6.09 m length of the middle contact wire was of sufficient length to have the regeneration turnoff as there was no load to keep it on so when the car passed onto the dead power section wire, regeneration was turned off preventing accidental energizing of the dead power section (similar to *Figure 11*).

Fig. 11

In preparation for pantograph operation, it was determined that the existing No-Bo section insulators that had a 355.6 mm [14 inch] underrun would cause bridging when the pantograph passed through it. The arcing from trolley poles and the subsequent damage to the arcing clip, tip and insulated underrun could cause carbon chipping of the pantographs so engineers looked into a different type of section insulator.

It was decided that a combination insulator specifically designed for trolley pole and pantograph operation was necessary and one that allowed power to not be interrupted during passage of the current collector. K+M designed a special diode section insulator for this type of operation consistent with the 6.09 m middle wire operation. Two insulators were used, one with the main diode and smaller diodes feeding the insulated conducting runners and the other section insulators with only small diodes. This arrangement was the same as the original section insulator arrangement except that the runners allowed the streetcars with pantographs or trolley poles to pass through with no interruption of current collection yet preventing bridging of the runners (*Figure 12*).

Figure 13 shows a schematic of the diode arrangement and power section separation. An interesting adaptation of this was used to provide automatic power section jumping during outages at the intersection of Broadview Avenue and Gerrard Street East where the four legs of the intersection are insulated diode section insulators and there is no feed at the intersection. Each street is fed by different feeder cables and the diodes at each insulator allow current to flow into the intersection but not out of it. This arrangement allows the intersection to have power in the event one of the power sections feeding the intersection goes dead (*Figure 14*).

Fig. 12

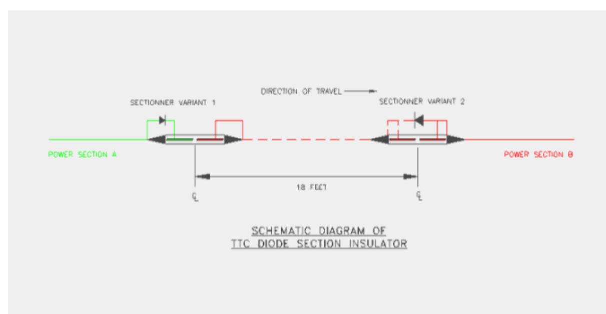

Fig. 13

Bridge Suspension and Protection

Standard suspension under low bridges has been with insulated wood trough to provide insulation between the trolley wire and a dewired trolley poles to the grounded bridge structure. The wire was directly attached to the trough with barn hangers and clamp ears. A new style

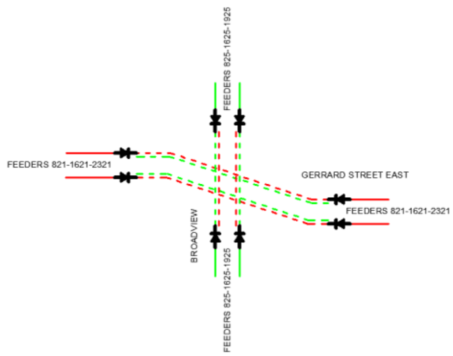

Fig. 14

trough with barn hangers and clamp ears has been used which is a U shaped fiberglass structural member connected to the bridge steel. An insulated rolling contact wire support is bolted to the trough and this provides an added measure of electrical protection and soft suspension. At the ends of the trough where the contact wire rises up to the next supporting span wire, the rolling support has a vertically curved curve rail to smooth out the vertical angle between the trough and the adjoining span. The trough and rolling suspenders are so arranged that both poles and pantographs can safely and easily negotiate the bridge and *Figure 15* illustrates this.

Fig. 15

Conductor Rail Installation

St. Clair Station West, which is an underground loop station with two inclines leading from the street has an overhead system consisting of wood trough and Universal Spacer Bar. At certain locations, the height of the station ceiling is very low and other locations very high and the trough is either bolted directly to the ceiling or suspended from it. Engineers looked at various options and decided to use aluminum conductor rail as the contact system for pantographs. There was to be a period of time that the wood trough/spacer bar system would be in service along with the new conductor rail system. This would be a completely new type of conductor and operating system for the Commission and they asked HNTB to do this design.

HNTB accepted the task to design the new OCS for the station area and HNTB and Commission engineers worked closely together. A major obstacle was the tight radius track turnouts and curves which were in place, some as low as 13.5 meters [44.29 feet]. Conductor rail must be pre-curved for tight radii and the minimum radius for Furrer + Frey rail was stated to be 40 m [131.2 ft]. It could be bent to 18 meters but running the trolley wire through it would be difficult. HNTB designed the bar as pre-curved segments in a chord fashion with the contact wire continuous through the bar. As the bars were not connected and jointed, jumper cables were used to provide electrical continuity. The bars had to be on either side of the wood trough and would alternate according to obstructions and locations at track switches.

Where the conductor rail ended and pantographs had no running surface, transition copper tubes were used and connected directly to the side of the wood trough. These were adjustable vertically to match the bottom elevation of the conductor rail. This allowed a smooth transition for the pantographs throughout the overhead in the station area.

Another design challenge was the fact that a large fire door was in place that had at one time operated. It had been taken out of service and kept in the up position and the wood trough and conductor bar run directly under and through the door area. Operations now requires that the doors be made operable again and provision has been made to install a door bridge that will break the overhead when the door is closed and allow pantographs and trolley poles to operate through the OCS when the door is up. There was some difficulty in having a conductor rail door bridge design as the original supplier insisted on designing the arrangement as well as supplying the material. Commission engineers searched for an alternative supplier and found one in KLK Rail Tech.

The conductor rail supplied by this company could be pre-curved to 14 m [45.9 ft] and they were willing to supply a door bridge and assist in any design effort by the Commission and their consultant. As it turned out, the door bridge arrangement as finally designed was a standard Impulse door bridge that was modified to have approach runners and an insulated bridge for both pantograph and trolley pole running.

The plan of the design is to have the existing trough and bar system in place and the bar system installed next to it. There will be phasing steps where the conductor rail will be changed and the trough removed in stages until only conductor rail remains. *Figure 16* shows the existing station area and *Figure 17* shows design details of the conductor rail and wood trough.

Fig. 16

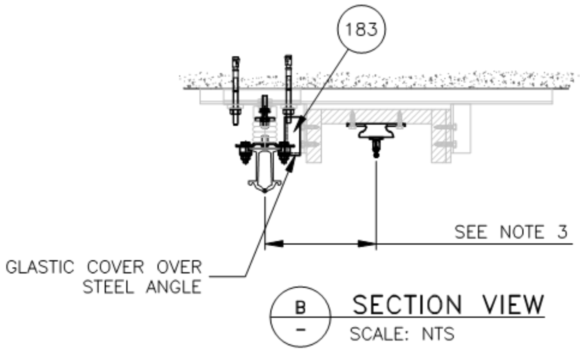

Fig. 17

Constant Tension

Commission engineers were aware of the need for constant tensioned overhead because of the extreme temperature range encountered in Toronto and explored options early in the design effort. A constant tensioned spring device from K+M/Pfisterer that applies a constant tension on the contact wire while the spring tension varies was chosen for trials (*Figure 18*). These springs have been in extensive use in Europe as a replacement to balance weights and have proven safer in areas of pedestrian traffic as there are no weights to fall down.

The system has been installed on the new Cherry Street extension of the 514 line and uses expansion rails from K+M that allow the contact wire to run through and move with expansion/contraction of the contact wire and is constructed as a simple overlap (*Fig. 19*). They allow a trolley pole and a pantograph to pass through and have been used on trolley bus lines in Europe for many years. Trial runs with pantographs and poles reveal a very smooth operation through the rails and the spring is keeping the contact wire in a constant tension of 890 daN [2,000 lbs]. This method will be used on other lines as well after the trial period is over.

Fig. 18

Fig. 19

The spring device is composed of two basic components, a take up spool and a spiral spring. The take up spool is a composite of a circular spool and a spiral cam which both rotate around a common shaft. The spiral spring is connected to the cam and the contact wire is anchored to a partially wrapped cable around the circular spool. As the contact wire expands and contracts, the cam and spool rotate compressing or expanding the spring. The changing force in the spring is compensated by the changing moment arm provided by the cam with a resultant torque system with a constant output force in the contact wire.

Constructing the OCS

The Commission maintains a large work force of electrical workers who build and maintain the existing power system. All overhead line work is undertaken by Commission employees who are trained, skilled journeymen linemen intimately knowledgeable with TTC's overhead system. All of the new construction for the conversion of pole to pantograph was undertaken by Commission forces and most of the work was done during the day with power on and streetcars operating. Night work was undertaken in locations where day time traffic made it impossible to maneuver the trucks without creating traffic jams or where long wire runs required the power to be killed.

The crews are governed by strict safety rules and wear personnel protective equipment including fall protection harnesses. Although chances of a linemen falling out of the tower are low, it is possible and the harness keeps the individual from doing so. Other protection includes hardhats, safety glasses, gloves, and arc resistant coveralls (*Figure 20*).

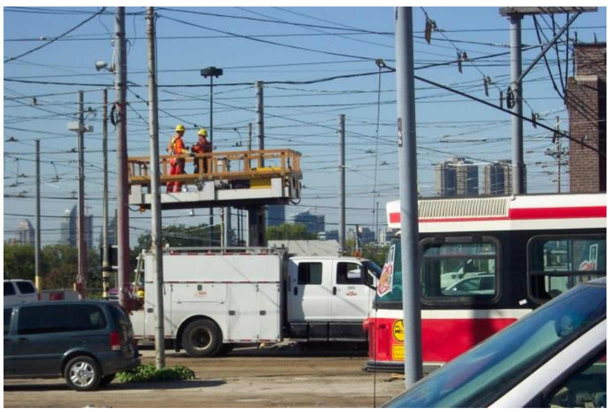

Fig. 20

Crews are made up of a foreman, two lineman and a driver groundman and work from a platform line truck as this equipment provides sufficient working space for two linemen, OCS equipment and tools.

One of the biggest advantages of the methods of construction and maintenance which are practiced by Commission line personnel is working the OCS while energized. In areas that can't be accessed during daytime hours requiring night work where the contact wire must remain energized, the crews can accomplish conversion work without affecting service in that particular power section. In carhouses and yards, this is essential as streetcars require power for auxiliaries such as air compressors.

The Commission also does conversion work on lines that have been temporarily taken out of service for track renewal and the overhead can be killed in these areas without affecting other parts of that particular power section. With no streetcar operation and the overhead killed, it can be removed and the line crews can rebuild the OCS to the new standards very quickly.

A distinct advantage of the new standard OCS is the use of high strength, non-conducting Kevlar rope. In intersections or other parts of the line where the contact wire is alive, these span ropes can be run over the existing wires without fear of short circuits or arc flashes as the wire is non-conducting. It can lie on top of the energized contact wire and the ground or be handled by personnel on the ground without fear of electric shock.

OCS Operational Issues

During the conversion process, several issues arose with the operation of pantographs. The pantographs have an automatic drop down feature that if damaged in any way, it drops down. The feature was set so that the pantograph would drop down but so quickly that it would slam into lock down and break the frame insulators. This feature has been modified to lessen the impact of drop down so that insulators are not damaged.

The new streetcars have a feature similar to the old PCC cars where the motorman could back the car using a controller at the rear of the car. Operators sometimes failed to secure the trolley pole rope and the pole would snag into a frog, bend the pole and damage the frog gliders. A pantograph would then run through the damaged gliders and get snagged. New rules were put in place that during the transition period, only poles could be operated in the yards. Frog runners have also tipped and caught pantographs but this is very infrequent and has been solved by more frequent monitoring of the areas of most concern and span wire adjustment.

The runners on the diode section insulators are positioned below the tension beams for the pantograph to run on without running on the bottom of the beams. Some installers have not completely adjusted the runner and they were too high causing the pantograph to run on the tension beams. Once the runner was properly positioned, the pantographs ran through properly and smoothly.

A buildup of carbon deposits from the carbon shoes and pantographs caused minor electrical tracking. When power sections were killed, indication to power control was that the section was still alive. Wiping down the runners stopped the problem but carbon would continue to build up. The runner insulating material was changed from fiberglass to ceramic but uneven wear problems occurred where the metallic portion of the runner would wear faster than the ceramic portion. An air gap insulator at the runner connection is being looked into and appears it will solve the problem.

Some arcing has occurred at the mid-portion of the insulator at runners where the two sections are fed from different power sections. This occurs when there is a large difference of potential between power sections and the streetcar is running through the insulator at full power. Magnetic blowout coils have been installed and this has solved the problem of arcing but does not allow a pantograph to pass safely through as the device hangs down. A different blowout with spread wing magnets has been tried but the magnets were not powerful enough and the engineers are looking at different types of magnets. In one instance, the arcing damaged the large heat sync diode so a decision was made to take it off of the insulator and hang it on the section insulator suspension spans. This also made the insulator lighter by reducing the weight.

The tension in the contact wire is full tension for tangents and long radius curves and is half tension on tight radius curves. Where the contact wires of the two different tensions merge at trolley frogs, the half tension wire can become slack in hot weather and a pantograph has pushed it up high enough that the horns snagged onto the full tension wire. This was rectified by putting spacers between the two wires beyond the trolley frog similar to a knuckle to keep the wires moving up together. The first knuckles were two adjustable steady arms u-bolted together and then a special spacer was created with an insulating oval rod and two clamps for contact wire attachment.

In general, problems have been more of an annoyance than systematic and pantographs have performed very well on the line. Unforeseen problems that have arisen have been addressed and these problems have been solved.

Conclusion

The Toronto Transit Commission is purchasing new Bombardier Flexity streetcars equipped with pantograph current collectors to replace the existing fleet of CLRV and ALRV streetcars with trolley pole current collectors. The first prototype Flexity cars are equipped with both pantographs and trolley poles. Existing cars and new cars will operate simultaneously until the new fleet of streetcars has been delivered and placed in service with existing streetcars being replaced as new streetcars are put in service.

The Commission's existing OCS was a traditional system adopted for only trolley pole operation. The system is being converted to allow both trolley poles and pantographs to run on it and when all pantograph streetcars are running, further changes will be made for only pantograph operation of the OCS.

Initially, trial installations were undertaken using different manufacturer's hardware with different consultants designing the installations. Line crews evaluated the hardware and ease of construction from the designs presented and recommended what hardware should be used. The steel span wire system was changed to Aramid span rope for ease of installation and safety. Engineers working with line crews developed a standard overhead system for TTC that the line crews would build to and that the consultants would design to.

Overhead fittings were designed for joint operation and new fittings and suspensions were created where appropriate fittings were not available. Lines are being converted by TTC line personnel changing out the old overhead hardware and installing the new material both during outages and with the contact wire energized and service running.

The use of diode section insulators was retained with the arrangement of spacing for preventing accidental regeneration energizing of dead power sections. The section insulators were equipped with conducting runners fed by diodes for all streetcars to pass through with power but without section bridging. They are designed for accommodating poles and pantographs.

A special arrangement for feeding the intersection of Broadview and Gerrard was implemented with diode section insulators to allow the intersection to have power if one of the two power sections went dead as the power feeds were through the section insulators.

Constant tensioning was implemented on the new Cherry Street extension of the 514 line using K+M/Pfisterer constant tension spring devices with trolley wire change clamps for the expanding overlap rails. This will keep contact wires at a tension of 891 daN [2,000 lbs] regardless of ambient temperature.

Several operational issues have occurred with joint pole and pantograph operation where pantographs have been snagged. Some of these have been due to pole dewirements damaging frog gliders which in turn have damaged pantographs. Adjustments have been made to prevent damaging the gliders and operator instructions for backing up cars have been issued to prevent pole snagging.

Electrical tracking on section insulators has caused false indications of the line being alive. Insulators on conducting runners have been replaced with ceramic material to reduce carbon buildup. Crews still clean insulators periodically to ensure tracking does not occur. Some arcing occurs at section insulators and arc blowout devices have been implemented.

Half tension trolley wire on curves when connected to full tension on tangents at trolley frogs has allowed some pantographs to push the wire too high and cause snagging. Spreaders have been installed between the two wires beyond frogs to make the wires rise up together.

The problems encountered are not systemic but nuisance and have been rectified as they have occurred.

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END NOTES

Fig. 1 CLRV Streetcar

Fig. 2 ALRV Streetcar

Fig. 3 Flexity Streetcar with trolley pole

Fig. 4 Flexity Streetcar with pantograph

Fig. 5 TTC designed carbon shoe for trolley poles

Fig. 6 Proposed articulated shoe for trolley pole

Fig. 7 Pullover assemblies

Fig. 8 Trolley frog deadend

Fig. 9 Trolley frog with gliders

Fig. 10 Adjustable crossing pan with gliders

Fig. 11 Original section insulator with diodes

Fig. 12 New section insulator arrangement with diodes

Fig. 13 Diode section insulator schematic

Fig. 14 Diode section insulator arrangement-Broadview & Gerrard

Fig. 15 Bridge protection fiberglass trough

Fig. 16 Saint Clair Station wood trough and spacer bar

Fig. 17 Conductor rail details

Fig. 18 Constant tension spring device

Fig 19 Constant tensioned overlap for poles and pantographs

Fig. 20 TTC linemen working

Table 1 Contact Wire Tension Chart