The Importance of Track Rope Slipping On Tramway Systems

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In most cases the tramway manufacture requires track rope slipping every twelve (12) years. Operators may ask why or wonder what will be gained by this process; this paper will provide insight to what has been found in the last round of track rope slipping in over a dozen tram systems in North America between 2005 and 2009.

Critical areas of concern:

- Final end attachments
- Bollard wood
- Broken wires
- Lubrication
- Vibration
- Contact with concrete
- Bronze profile wear
- Corrosion.

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Introduction

As we all know, have seen, and can testify, wire rope is a very resilient mechanism. The design and manufacturing of wire rope allows for more abuse, neglect and mistreatment than any other mechanic or electrical component found on aerial transportation systems. It continues to provide support or movement through all sorts of physical conditions, environment conditions, and a wide range of wear characteristics.

Due to their magnificent performance for the past 150 years or so, the present day condition of track ropes is easy to forget or overlook, as people tend to concentrate on the moving, circulating, heat generating, and heavy wear components. They forget about the "stationary" keystone of the tramway itself, the track strand.

In the past five years I have been involved in slipping track ropes on some 13 trams in North America and herein would like to share a collective summary, the results of which are quite repetitive between all installations. It is interesting to look back and see the same general characteristics regardless of the tramways environmental or atmospheric conditions. I have found similar results at trams that run 120 trips per day and 40 trips per day, in the "fresh" air of Alaska and the "pollution" of Atlanta, in the frigid North East to the arid desert.

Tramway Code Requirements

ANSI B77.1 – 2006

A.4.2.4 Relocation

The distance to be moved and the frequency shall be as recommended by the track cable manufacturer or ropeway designer.

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A.4.2.3 Repair / Replacement of track strand

This section discusses the occurrence of broken exterior wire(s) and the need for the approval of the strand manufacture, ropeway manufacture, or a Qualified Engineer to make any repairs.

It also describes the limitations of track strand service life when there is a reduction of the nominal metallic cross section due to wire breaks, wear, or any corrosion amounts to 10% in any length of 200 strand diameters or 5% in any length of 30 strand diameters.

CEN and BAV Swiss code

Track rope relocation is to occur every 12 years.

Aerial tramway manufacturers' operation & maintenance recommendations past and present Von Roll / Garaventa / Doppelmayr

Older trams had various recommendations for shifting. Some were every 6 years and others were every 12 years. Newer tram manuals have changed the recommendations with the initial track strand relocation after 12 years, and then every 6 years after the initial shifting has occurred. It is up to the manufactures' engineers to consider the operational characteristics of each machine separately and then determine a prudent approach to ensuring safety. The consideration of fatigue cycles is really the key factor.

The two prominent reasons for track rope shifting are as follows:

1.) The portion of the track rope that is subjected to cyclic loading (affecting fatigue life) is to be relocated to an area with lower exposure to such loading cycles. The distance of rope shifting must accommodate all highly stressed portions of track rope to become accessible for electromagnetic inspection (i.e. towers, roller chain area and terminal saddles).

2.) To achieve accessibility for proper electromagnetic inspection (MRT). This type of electromagnetic testing shall be completed prior to and after each relocation project.

The included benefit in the 12-year track strand shifting schedule is that it is an excellent time to renew the poured socket end connections. The BAV code for socket renewal is 18 years and manufacturers often recommend 12 years for renewal and inspection.

<u>Opposition</u>

Not every tramway operator completely agrees with or follows the code or manufacturers' guideline on track rope shifting. Some would argue that the relocation of the track rope subjects the track strand to reverse bending by taking track strand that was accustom to a positive bending curve on a saddle and moving this section to a negative bending caused by the passing of the carriage sheave loading moment.

Some think that the cost and downtime involved is not justified by the final outcome of the project. Many do not see the difference of the before and after benefits as it does not change the tram operation in any manner.

Owner/Operators want to know what they will gain in this process. Why are they slipping perfectly good rope down hill? Why don't we wait until we see a problem?
Ultimately their concern is what happens when we deplete their reel of spare rope, as they know this means a large financial burden on the operation when the time comes for new track strands.

While there are tramway systems across the globe that have not prescribed to following the manufacturers' recommendations, and have managed to provide safe operational conditions to their public, it remains that our engineers believe the best situation considering tramway safety, track strand life, availability of inspection, wear characteristics and lubrication are better met through a diligent track strand shifting and inspection routine.

Actual findings

During any track strand shifting, inspection of the rope coming off the bollard into the system shall be done in conjunction with the shift. This allows for any clean-up, grinding or mitigation prior to the anomalies being set on a terminal saddle or other inaccessible location.

After the shifting is complete, detailed visual and MRT inspection shall be made of each section of rope that was moved off a saddle or structure. Special attention must be made at the terminals and roller chain areas. If a section of track strand is not accessible to MRT than detailed visual inspection must be completed. During any MRT inspection a 100% loaded cabin should be used to allow for maximum rope travel on/off saddles and roller chains to provide for the greatest exposure to the critical areas.

Based on track strand shifting projects in over a dozen tramway systems in North America between 2005 and 2009, the following is a list of anomalies found in multiple systems.

1) End Clamps

    a) In review of original size and quantity against current standards, many installations are found to have undersized clamps. The remedy is to increase the quantity and size of the clamps as well as reinforce the anchorage frame.

2) Sockets

    a) The age long debate is how long is a socket good for? In most cases it is recommended to renew the poured sockets every 12 years in conjunction with the track strand shifting. Some minor oxidation has been found, some socket cone movement "pull", and some tilted cones indicating movement or bending of the track strand in the socketing process.

3) Bollard Wood

a) The lining material on bollards is found in various states of decay or crush, dependent on the atmospheric conditions and the wood selection in the original construction. In several cases it has been required that the wood be replaced prior to the track strand shifting.

b) Bollard conditions are often left unattended, with sand, concrete, dirt, snow melter/salt, and grease all building up on the crown of the bollard and working into the coils of track strand. This makes slipping the track strand very difficult on the bollard wood as well as contributes to unnecessary corrosion, and wear. On vertical bollards leaving 1-2 mm gaps between each coil can aid in maintaining a cleaner and drier condition.

4) Broken Wires

a) Obviously, the idea is to facilitate 100% of the length of track strand to MRT. In doing so, broken wires can and will be located.

b) Proper documentation and repair of broken wire is critical to continued safe use.

5) Lubrication

a) This is one area where the environmental conditions do play a key role in the long-term effect of the lubrication. Operators have to be vigilant at monitoring the track strands to determine if the frequency and quantity of cable lubrication is meeting the purpose. There are multitudes of cable lube suppliers and choosing one over the other requires testing and research. Many are good and in most cases I think the issue is application, not quality.

b) Routine greasing of the saddle profiles is important for normal operation to allow smooth and even track rope movement on the saddles. It is equally important for track rope shifting. Without clean profiles and adequate lubrication the tracks can become uneven with radical tower saddle movement.

6) Vibration Wear

a) In some cases the harmonics of the track rope coupled with minute movement of track strands in fixed stations has been found to lead to minor scratching or abrasion wear when in contact with any steel member of the station. Additional care has to be taken to eliminate this contact when it is found and the track strand has to be dressed to remove any notching or scratches.

b) Another point not to miss during inspection is the area of rope that once had brackets, switch bodies, station end bumpers etc. in contact with them including slack rope carrier clamps. All of these are likely spots to find abrasion and or corrosion.

7) Contact with Concrete

a) Here we can see a negative chemical reaction between the calcium in concrete and the steel wire of the track strand. This will lead to localized corrosion that must be addressed by polishing the track strand and mitigating the contact area. We try to place .25" spacing strips to create clearance in these areas.

8) Saddles

a) While it is true that bronze profiles have an extremely long life cycle for a full load contact wear component (25-40 years) they must not be overlooked during the inspection and or track strand shifting intervals. It is difficult to visually recognize vertical wear of the bronze profile or horizontal alignment as the variances are small and the components are usually covered in grease.

b) The derail clamps have been found to cause considerable damage on various track strands. While there are clearances designed in these clamps, outside influences such as wind load, production and erection tolerances, and undetected brass wear may allow the track strand to come into heavy sliding contact with the steel clamps or even the mounting hardware.

c) Another natural enemy to the track strand is foreign material in the bronze profile. Past history has found everything from the steel ball of the grease fittings, busted tips from case hardened taps, to rock fragments from localized blasting.

d) Any exterior track strand damage, markings, scratches, abrasions, or other defects must be addressed immediately! This type of damage creates stress risers, known as "notch effect", and if left unattended will be the root for future wire ruptures. Typically this exterior damage can be polished or ground by a qualified wire rope specialist to remove the damage and smooth the affected area.

e) Any track strand shifting on steel profiles must be avoided. It is recommended to detension the rope before any shifting to alleviate the high bearing pressure and any chance of foreign material or steel transfer which leads to hydrogen-induced stress cracks. In some cases we have modified terminal saddles to accept new bronze profiles.

9) Corrosion

a) The bollard wraps and the excess reel;

i) Usually the worst amount of corrosion and the hardest to maintain. Also the worst environment being damp, wet, and confined with no air flow.

ii) Excess reels are critical as they hold the spare track strand for up to 48 years. If the rope on the excess reels is not routinely protected and cared for the track strand can suffer from excessive corrosion and become useless.

iii) It is worthwhile to note the extremely corrosive agents used in deicer and salt. If the operators are not careful these agents wind up on the bollard, excess reel, end clamps and anchorage along with the snow and collectively create serious damage.

b) The main body or length of the track strand

i) Not as critical because in most cases the oxidation is merely surface rust and can be easily mitigated with a thorough cleaning and proper lubrication.

ii) Without a periodic thorough cleaning of the track ropes water can be trapped beneath multiple layers of wire rope lubrication. Some wire rope lubrication dries like a varnish finish and the corrosion and moisture sits hidden and un-addressed.

iii) Slack rope carrier locations must be inspected after any relocation of the carrier. Manufacturers' recommend slack carriers are relocated each year to avoid the chance of corrosion in the clamp area. Attention to cleaning and lubricating the track strand after any shifting is necessary.

c) The end attachments

i) Sockets -Has the socket been properly protected to prevent intrusion of water? It is impossible to inspect so protection is critical. History tells us that failure may and will occur if nothing is done.

ii) End Clamps - In most cases this is not an issue. However in some cases the moisture of the surrounding area can lead to oxidation especially when combined with snow deicer.

10) Roller Chain Saddles

a) The roller chain and saddle must be evaluated at the planning stage of a track strand shift. The saddle track must be inspected for wear limitations and the chain must be reviewed for sufficient design parameters. The manufacturers' engineers may recommend modification to the roller chain and saddle to improve the design function of the system.

b) The roller chain area is certainly a high potential area for broken wires and internal failures. This is because the design parameters for the roller chain radius are smaller than tower saddle radius requirements, thus the bending moment is greater. Inspection before, during and after any track strand shifting is critical in order to identify damage and insure the integrity of the track strand.

11) Past Misgivings

a) There is any number of occurrences that either happened during installation, an accident, general operation & maintenance or other subsequent rigging projects. Evidence of hammering, weld splatter, 6 strand rope abrasion (throw over) and previous broken wire locations have all been discovered or rediscovered. Sometime the history of these areas is known and in other occurrences the history has been lost and “Wire Rope Logs” are missing this data so it leaves unanswered questions.

Conclusion

Without the preventative maintenance of track strand shifting being completed according to schedule, we cannot possibly know the extent of damage that may exist or know the true condition of a track strand section. Furthermore; without thorough inspections during the track strand shifting process unsafe or dangerous conditions may go undetected.

There is enough evidence that substantiates the reasoning behind both the code and the manufacturers’ recommendations with respect to track strand shifting and maintenance. This evidence is routinely found on both fixed anchor spans and counterweighted tension systems.

Key components that manufacturers’ engineers use to determine the recommended interval of track strand shifting are as follows; when a specific component is known to be outside the accepted “norm” than the engineer may prescribe a shorter more restrictive interval.

- Roller chain radius:
  - BAV code min 100 x d if excess length is provided for 6 shiftings (6 yr. cycle)
  - BAV code min 150 x d if excess length is provided for 3 shiftings (12yr cycle)
  - CEN code 150 x d (rope dia.)
  - ANSI 100 x d or 1200 x Z (largest outer wire dimension)
- Tower saddle radius
  - BAV code 250 x d
  - CEN code 300 x d
  - ANSI code 1200 x Z (largest outer wire dimension)
- Saddle profile lining material (e.g. bronze, plastic, steel)
- Number of cycles per year <20,000 or 55 per day
- Percentage of loaded cars versus design load
- Rope design, specifications, wire grade
- Safety factor or rope
  - BAV code 3.25
  - CEN code 3.15
  - ANSI code 3.0
- Environment – corrosion
- Lubrication saddles and roller chain
- Permanent track rope lubrication of roller chain area
- Tensioning system
- Ratio of rope tension to max. carriage wheel load (60:1 code)
- MRT accessibility and past results

Should any of the parameter values change over the life of the tramway, a precise analysis of the shifting interval shall be completed to determine if changes to the interval is warranted. Usually there are changes to the operation or tramway system that affects the analysis process. Most drive upgrades increase line speed and decrease docking time, thus increasing overall cycle counts. Tramways become more popular with advertising, population growth, or system upgrades and loads or percentage of loads increase. Most tramway environments do have corrosion so this parameter must always be checked.

We simply cannot avoid the fact that the accumulated cycle count never stops. The clock is not restarted after the initial 12 year shift, each and every trip counts towards the fatigue life of the rope. The cycle count parameter given above <20,000 per year is considered for a 12 year interval. That is 55 trips per day for year round operations; there are several trams running 120 to 170 trips per day, which pushes their yearly cycle count to > 44000. This in itself may constitute a shorter track strand shifting interval.

The problem is that once fatigue life of the ropes is approached, deterioration takes place rather quickly. Fatigue failures are a direct result of the accumulated number of load cycles. In one instance the track strands had been shifted for what had been believed the last time (little to no spare rope remained) and within 3 years numerous broken wires (29 breaks in 1 rope) both internal and external in the roller chain area created a situation where an emergency shifting was called for with special extenuating requirements and design engineering approval of both the tramway manufacturer and the rope supplier.

The codes and requirements stated in this paper are for reversible jig-back tramways and are not specifically for bi-cable (2S) or tri-cable (3S) systems as they are subjected to an even greater number of load cycles. This means the shifting and inspection intervals are shorter and several of the design codes are more stringent.

Simply put we must continue to shift track strand on schedule, we must be diligent in our inspection process, and we must locate and mitigate any damage to the track strand, in order to preserve a safe and manageable track strand condition for our public passengers.

With every track strand shifting there are various types of damage or anomalies to be found, that can and should be addressed and corrected.