SEPTA's Broad Street Subway Propulsion Control Box Retrofit – Post Installation, Realized, & Hidden Benefits

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SEPTA's BROAD STREET SUBWAY (BSS) CAR PROPULSION SYSTEM RETROFIT

Abstract

In 2001, the SEPTA Broad Street Line B-IV Vehicles were experiencing car availability issues due to declining propulsion system mean-distance-between-failure (MDBF) and increasing mean-time-to-repair (MTTR) figures. The major cause of our equipment reliability problem was the aging General Electric (GE) propulsion control box equipment that was no longer supported by the OEM. After thorough investigation and consultation with LTK Engineering Services into the increasing capital and operating expenditures along with decreasing fleet reliability, SEPTA decided to acquire a new propulsion control box instead of upgrading the existing one.

SEPTA awarded the contract to a Germany-based company named Vossloh Kiepe in 2005 and completed installation on the 127 car fleet in 2011. We would like to share some of the realized and hidden benefits of our retrofit. Expected benefits to the project were realized in that the MDBF has increased and the MTTR has decreased significantly along with cost savings from the new regeneration functionality. Some of the unexpected benefits were decreased failures of our DC traction motors due to the new processor controlled technology and additional energy cost saving due the Insulated Gate Bipolar Transistor (IGBT) power conversion topology. These benefits will be expanded to inform Transit Agencies of the better than expected results of our conservatively budgeted project.

BSS Line and Fleet Information

The first set of rail cars for the Broad Street subway was built in 1927–28 by the J.G. Brill Company. The Pressed Steel Car Company supplied an additional set in 1938. The first set had the second longest lifespan of any subway car in Philadelphia. The Market Street cars built for what ultimately became the Market–Frankford Line have the longest lifespan. Although the line was a host for the Urban Mass Transportation Administration's (UMTA) State of the Art Car program, real replacements for the Broad Street cars did not come until 1982, when SEPTA introduced new "B-IV" cars built by Kawasaki. The B-IVs are currently the only cars operating the line, though a small number of historic cars can be seen in the yard at Fern Rock (1).

Figure 1- Broad Street Line Map

Here is a basic overview of the current B-IV vehicles serving the Broad Street Subway:

Builder	Length	Year Built	Quantity	Mode of Power (present)	Seating	Fleet No
Kawasaki Heavy Industries	67' 6"	1981-1983	76 Single	IGBT Chopper Controlled DC Motor	65 Single	501-576
			49 Double		62 Double	651-699

Table 1- B-IV Vehicle Information

Figure 2- BSS B-IV Vehicle

Project Overview

Project Justification

In 2001, with the assistance of LTK Engineering Services, SEPTA analyzed the condition of vehicle equipment and performed statistical analysis to define the root causes of excessive propulsion failures (most commonly referred to as "blue light" failures).

Prior to 2001, analysis of cam controller refurbishment with both Westinghouse (WE) and GE at the end of the Market Frankford Subway Elevated (MFSE) M-III vehicle overhauls indicated that it would have been cheaper to purchase new controllers than to refurbish the existing M-III vehicle equipment. When the issue of the B-IV controller came up, there was no question about overhaul but we needed to have an independent justification.

A combination of root causes were found to contribute to the excessive "blue light" failures which subsequently provided enough information for LTK to create a comparison chart which compared the following four options:

	General Description
In-kind Overhaul	O/H similar to the previous VOH program with following additions: • Harness replacement • Power Cable replacement • Complete Cam overhaul or replacement
Overhaul with separate Reverser and P contactors	Same as in-kind overhaul, with addition of: • Separate enclosure for a new reverser and P-contactors • Associated cabling and wiring • Carbody mounting interfaces
Update to Computer Controlled Cam (CCM or E-Cam)	Complete replacement of the 17KG411A1 with a new enclosure (using the same mounting points) with a computerized cam package and replacement of the 17KG412A1 electronic group with the new enclosure.
Replacement with IGBT AC Drive	Replacement of 17KG411A1, 17KG412A1, both 17EWF resistor assemblies, and traction motors with an IGBT drive.

Table 2- LTK Comparison Chart

Project Options Decision and Specification

The original SEPTA specification was written for a computer-controlled cam controller but at first go-around, SEPTA expected that GE was going to be the only bidder. When the Specification was sent out for industry review, both Vossloh Kiepe and a Czech firm indicted interest in a Chopper design. The Specification was revised to allow Chopper control. Kiepe won the bid, GE was second at about $5M higher with the cam controller, and the Czech firm came in at about $20M but they included new motors. The DC chopper controller system was awarded to Vossloh Kiepe headquartered in Germany in 2005.

Vossloh Kiepe had already provided SEPTA the new AC propulsion system for our 18 car SEPTA PCC2 fleet rebuilt by Brookville and was also providing major systems on our 38 car Trackless Trolley fleet acquisition with New Flyer.

This project would have started much earlier but was held up by delays in our LRV microprocessor project. Until money was moving in the LRV project, no significant funding was going to be tied up in another project.

The scope of work detailed that the equipment would replace the present KM 48 cam control system, the 17KG412 Electronics Group, and the 17Fl219 Rate Setting Card originally supplied by GE. Also, all items under this contract would be supplied by the contractor, in kit form, for installation by SEPTA.

Under a Reuse of Parts clause, SEPTA would allow venders to reuse certain original parts by stating that “SEPTA will refurbish and reuse the original Field shunts, Grid resistors, speed sensors and speedometer where applicable. Field shunts, grid resistors, speed sensors and speedometers (IF APPLICABLE) shall be rebuilt or reconfigured or furnished new by the contractor if the present units are not compatible with the replacement controller” (2).

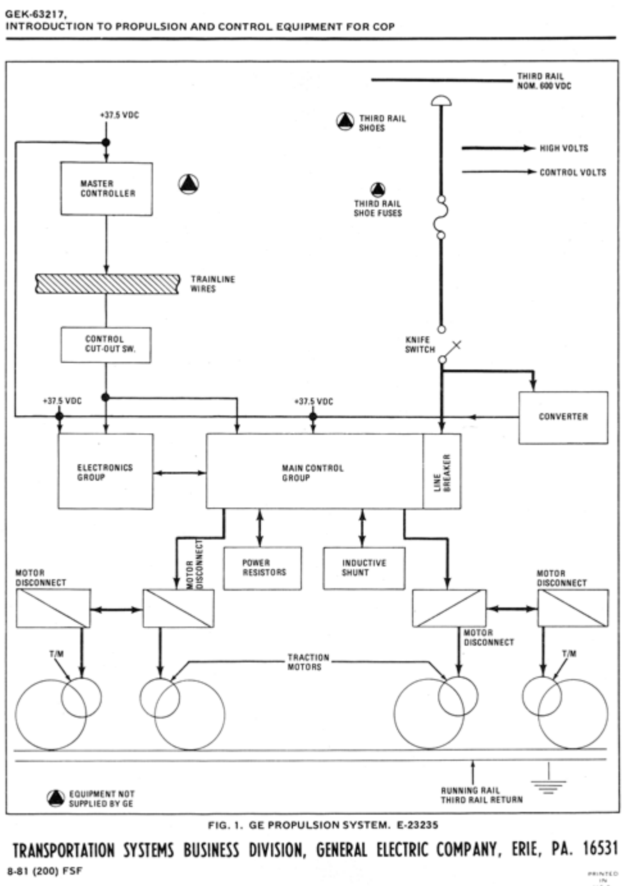

Figure 3- Original B-IV GE Propulsion System Overview

Project Deliverables

The following major contract deliverables were specified for this contract:

1. 136 Propulsion Control Assemblies (9 spares)
2. On-car and back shop diagnostic equipment with training
3. Maintenance documentation
4. Software documentation
5. 10 spare sets of electronic modules and circuit boards
6. Structural analysis with instructions for reinforcement where required
7. Installation procedure
8. Performance test plan

There have been a total of 4 contract changes to the original order which are as follows:

1. Contract language clarification about test equipment (No Cost).
2. Purchase of anti-rollback feature and associated components.
3. Purchase of additional heavy maintenance training.
4. Purchase of new MZE300 central unit modules were needed to assure the PCM sub-system computer was operating at peak speed efficiency with full memory capacity for current and future system upgrades.

Project Costs

Contract Price w/ Change orders	$11,381,264
Septa Installation Costs	$1,381,927
Total SEPTA Expense	$12,763,191

Post Installation Status

As of 3/31/2011, the entire fleet was completely retrofitted. Currently, Vossloh Kiepe has one technician on-site at Fern Rock Car Shop to handle warranty issues.

Realized Benefits

As originally stated in the LTK evaluation report (3), a reduction in GE 1264 type traction motor (TM) damage due to improved self-protection capabilities was realized as evidenced in the dramatic drop of motor operational data. In fiscal year (FY) 2010, when new controllers were just starting to be installed, 108 TMs were replaced due to operational failures. In FY 2012 after all the controllers were installed, only 35 TMs were replaced; this comparatively totaled an approximate cost savings of

$220K a year. The actual savings could be multiplied by a significant factor considering other cost savings related to vehicle troubleshooting, TM replacement, and transport costs, some of which can be seen in the Table 3 buy back table.

Motor failures are reduced because the IGBT chopper can remove power from a motor that is just starting to flash much faster then opening a contactor. This reduces the damage to the flashing motor and prevents damage to the other motors connected in parallel. Apart from the raw cost data, an additional tell-tale sign of cost savings was the reduction of needed overtime due to the decrease of motor failures.

Another realized benefit was an increase in system MDBF or reduced “blue lights” as seen on figure #4 which displays propulsion faults recorded in SEPTA’s Vehicle Maintenance Information System (VMIS) before, during, and after installation. Eleven months of fault data from before installation of the new controller shows an average of 95 propulsion related faults per month and eleven months of recorded data running with the new controller shows an average of only 35 faults per month.

Also, new electronic circuits are more reliable than the 30-year old heavily maintained circuits. Additionally, the new automated bench test equipment and training should result in less cost to repair any circuits that fail. When there are failures, better diagnostics result in greater vehicle availability due to less downtime. Better diagnostics allow the mechanic to identify and correct failures quickly. Even intermittent faults are being repaired without repeat blue lights. Availability is especially important on this line, since in addition to heavy use by work and school commuters, it gets high use to the Philadelphia’s sports complex located at the AT&T station.

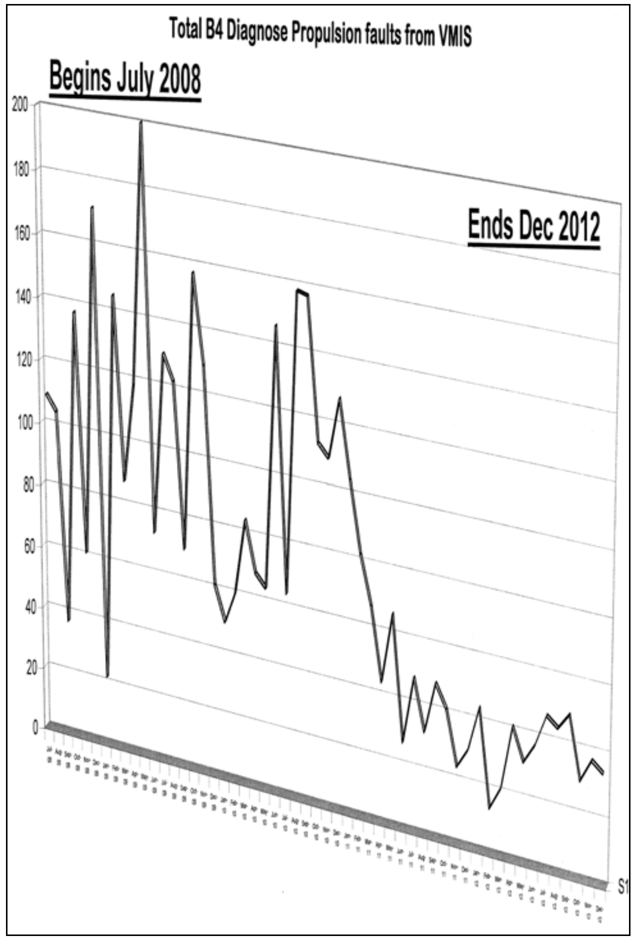

Figure 4- B-IV Propulsion Fault Chart

Hidden Benefits

Technological Energy Savings

SEPTA realized a significant energy cost savings (approx. #858K per year) just by converting from a cam controller to a DC Chopper.

This new chopper system is more efficient since only the instantaneous voltage that is needed by the accelerating motors is applied. During acceleration, as power is applied, it does not go through resistors as it did in the original system. Instead the chopper mechanism is able to control the amount of power used to accelerate, allowing almost all of the power to be used in acceleration with very little being wasted (3).

For cam and resistor control, the control of motor voltage is obtained by wasting energy in the control resistors. At initial start, the motor voltage is low (effectively zero) and almost all the line voltage is dropped (wasted) in the starting resistors. As the speed increases, the motor voltage increases and the energy waste decreases. With solid state IGBT control, the line voltage is reduced to the needed motor voltage with no loss. Both approaches allow the control of traditional DC traction motors. An added benefit of solid state control is the elimination of the voltage surges inherent with stepped resistor control.

Even as far back as 1972, during trial car operations, it was shown that chopper controlled cars consumed about 78% of the power consumed by the cam controlled car (4).

With the addition of computer control, it was possible to have KIEPE incorporate the FTA mandated rollback feature for a change order of less than $50,000. This would have cost ten times more if SEPTA had to go out for bids for the feature.

The high speed propulsion computer can now monitor the current from each truck, allowing rail gap detection. By reducing propulsion before entering a gap, arcing at the third rail shoes is eliminated, thus reducing the damaging voltage spikes normally produced.

The computer interface allows the propulsion and braking rates to be adjusted on the rate track during inspections. When all the cars in a consist accelerate and brake at the same rate then there is less stress on the couplers.

Squealing Brakes or Noisy Resistors

An unexpected consequence of reusing the brake resistors was that the 1250 HZ pulse frequency of the IGBT chopper that flows through the resistors created a nuisance noise that sounds like “squealing brakes’. While many operators and passengers alike thought that we were having brake troubles, it was actually just our resistors squealing. When we enabled regenerative braking, the “squealing brake” noise stopped because the energy was sent back into the 3rd rail and not dropped across the brake resistors. Therefore, enabling the regenerative braking functionality led to an additional power savings ($40K per year , 4-month sample), and it also took away SEPTA’ squealing brake resistor problem.

Figure 5 - Grid Resistors

Other Benefits

Buy Back

SEPTA intends to keep the B-IV vehicle an additional 20 years. Without performing an exhaustive analysis of cost savings, one can see by looking at Table 3 that SEPTA’s choice to retrofit the propulsion system is well on its way to being bought back.

Buy-Back without Regen	14.88 years
Buy-Back with Regen	14.21 years
Buy-Back with Regen + Motor Savings	11.41 years
Buy-Back with Regen + Motor Savings + Maintenance Savings	9.51 years

Note: Regen period has small sample size of only 4 months

Table 3- Equipment Buy Back Period

Project Lessons Learned

1. Regenerative braking was left in a disabled state on the B-IV cars due to the fact that electromagnetic compatibility with SEPTA’s signaling system was not verified. The lack of an electromagnetic compatibility plan in the specification caused the system to go untested until a later date. SEPTA contracted with LTK Engineering to perform an EMI Impact test of regeneration. This cost SEPTA several years of unrealized

savings due to the regenerative braking being disabled. At a minimum, it is recommended to require compliance to APTA's Standard for Development of an Electromagnetic Compatibility Plan (APTA SS-E-010-98) in your specification and to ensure tight coordination between in-house agency departments (i.e. Signals, Power, & Track) before and during the project so that savings can be fully capitalized on.

2. The original specification was up-scoped from a cam controller type to a chopper controlled type retrofit and did initially call for an installation rate of 2 per month; however, this rate was requested to be changed by vehicle maintenance management to 8 per month without knowing the actual manpower required.

With the additional work needed on the vehicle carbody frame as a result of structural analysis findings and the work required to replace a cam-controlled system with a chopper controlled system, it would require additional installation manpower that was not in place. When we realized we could only install 2 per month utilizing the existing workforce, we asked Vossloh Kiepe to change their delivery schedule, but that re-quote number was way too high requiring an approximate $500K contract change order. Also, since the specification called for a 2 year warranty, we didn't want our equipment to fall out of warranty while most of the units were still in crates We mitigated the risk by adding about 6 additional heads and eventually were installing about 5 per month. In the end, the aggressive installation schedule seemed to be the best choice, but it would have been better to address installation schedules in the contractual language so that if there were any significant changes in installation manpower it would be mitigated by placing the onus on the contractor and not the authority.

3. Project success went way beyond partnering in that all levels of SEPTA were involved in the project. SEPTA's Engineering and Maintenance personnel (supervisory and unionized) worked with a synergy and with a sense of ownership to allow this project to meet its full potential. Organizational alignment was fully realized.

4. There was a healthy friction between Vossloh Kiepe and SEPTA over the conditions that would cause a blue light to occur. We wanted minimal blue light occurrences and they wanted maximum blue light annunciations in order to provide maximum protection for their equipment. As the pilot cars were being tested and further software refinement was being performed, our different perspectives helped to create a synergy that allowed us to meet in the middle as far as the annunciation of blue lights was concerned. This example highlights the importance of having engineering personnel familiar with the operation and maintenance of the rail vehicle intimately involved with the vender during on-car software development. Many software logic decisions can only be realized in the actual operating environment which should be jointly decided on.

Vender's Experience

While speaking with Vossloh Kiepe about their breadth of project experience, a couple of interesting project ideas/options were discussed that could assist in defining the proper project scope to help an agency fit a retrofit into its available budget:

1. Vossloh Kiepe stated that one of the reasons companies have traditionally avoided the retrofit from DC motors to AC motors was due to the need to replace the gear box. Vossloh Kiepe stated that with modern software tools it is possible to fit almost any DC motor torque/speed diagram into an AC motor enclosure.

2. German Transit Authority BSAG Bremen awarded Vossloh Kiepe a contract to replace half of their 50 car fleet GTO-type traction inverter with an IGBT-type with new motors so they could utilize the removed components to solve the obsolescence problem they were having with their cars.

Gratitude

A special thanks to LTK and Vossloh Kiepe for providing information in support of this paper. Also, much thanks to Ron Mikulski (SEPTA Rail Vehicle Engineering Manager - Retired) for supporting me with project history information.

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