EVALUATION OF WIRELINE ECP BRAKING AND DP ON THE ERMELO-RICHARDS BAY COAL EXPORT LINE

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INTRODUCTION

A description of the operation

The Ermelo-Richards Bay operation conveys primarily export coal, at a rate of some 74 million net tons per year. Two types of cars are in coal service. The older generation, designated CCL^{-1} and CCL^{-3}, grosses 176 000 pounds, or 22 tons per axle; the more recent generation, designated CCL^{-5} and CCL$^{-7\text{ through }13}$ grosses 229 000 pounds, or 28.7 tons per axle (the different series distinguish minor design variations only).

Most of the coal traffic, at either 22- or 28.7 tons per axle, originates at twenty-two loading sites, the most distant located 108 miles from Ermelo. It is collected in 100-car trains, hauled by four six-axle 3kV direct current straight electric locomotives to Ermelo. A further small amount of coal traffic originates at three loading sites on 22-ton per axle branch line, the most distant located forty-four miles from Ermelo. It is collected in two fifty-car trains, each hauled over a short length of 2 percent ascending grade by six six-axle diesel locomotives to Breyten. There the two trains are combined into a single 100-car train, hauled by the same six diesel locomotives to Ermelo.

At Ermelo, the 100-car trains are combined into 200-car trains, for the 263-mile journey to the harbor at Richards Bay. This segment is electrified at 25kV alternating current. The trains are currently worked by head end locomotive consists, either six six-axle Class 7E1s at 138 tons each, or four six-axle Class 11Es at 185 tons each. All locomotives are equipped with dynamic braking.

Either the 200-car trains convey all 229 000 pound cars, or a leading block of one hundred 229 000-pound cars followed by a trailing block of one hundred 176 000-pound cars. A holding brake (remote-controlled retainer) is required on one hundred cars, because the ascending and descending grades are asymmetrical. Only the 229 000 pound cars have holding brakes: They must necessarily always lead. The 200-car trains therefore gross between 20 300 and 22 900 tons, depending on the car mix.

A full description of the design philosophy of these trains was given by Van der Meulen & Lombard (1988) and Van der Meulen (1989), shortly after their introduction into revenue service: Subsequent learning follows.

Problem issues

The Ermelo-Richards Bay operation includes a challenging fusion of North American-oriented long, heavy trains, and European-oriented signaling. It has experienced two sets of problems on its 200-car trains in this environment.

First, those related to the physical limits inherent in air brakes—relatively slow propagation, which tends to lengthen stopping distance, and non-uniform distribution of brake force, which tends to abuse car wheels thermally. Braking within prescribed (maximum 4000 feet) stopping distances demands relatively high brake ratios (13-20 percent loaded, 70 percent empty). At the relatively small brake pipe reductions (a 6½-psi minimum, sometimes plus 1-2 psi) typically used to maintain constant speed on long descending grades, an equalization system may induce unintended car-to-car brake force variance. Figure 1 shows an example of mean wheel temperature, per truck, for a 200-car train passing a measuring site on a long descending grade (the authors recognize that mechanical variances confound the issue). Furthermore, despite the many indispensable attributes of direct release braking, it is difficult to curb the poor train handling practices sometimes encountered through grade inflections, which may aggravate thermal abuse of wheels.

Second, those related to high tensile- and compressive longitudinal forces, due to non-uniform distribution of brake cylinder pressure, and due to high head-end tractive effort, both of which increase drawgear distress or incur the risk of derailment. The quasi-static drawbar pull on the ruling ascending grade is in the range 360 000 to 400 000 pounds. The relatively high brake ratios are also suspected of contributing to derailment following deliberate or undesired emergency brake applications.

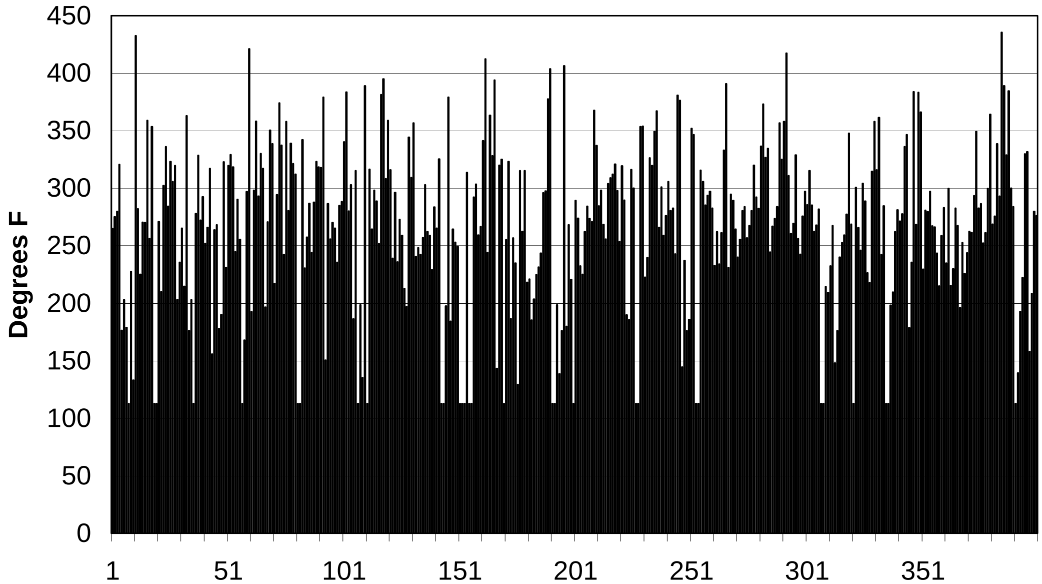

Figure 1: Temperature by Truck Number

The potential for problems was recognized during design as being inherent in the early 1980s technology, and accepted as a challenge to be overcome in the course of revenue service. Nevertheless, despite the problems mentioned, the operation ranked world's lowest cost per net ton-mile in a 1994 Mercer Management Consulting benchmark study. The foregoing self-criticism thus provides a necessary basis from which to advance a systemic design that was arguably as good as it could have been at the time.

Possible solutions

Initially, traditional radio-based distributed power only was contemplated, to contain longitudinal forces. Clearly, separating the locomotives into two or more consists would significantly reduce such forces. A series of tests was therefore conducted during 1997 and 1998, to examine the in-train forces and brake system performance likely if it implemented traditional radio-based distributed power. A significant improvement was measured on trains powered by both two and three locomotive consists. However, this solution would only have partially addressed air brake physics limits regarding transient non-uniform distribution of brake cylinder pressure, and would not have addressed the car-to-car brake force variance at all.

During the gestation period of this case, ECP braking fortuitously appeared on the technology horizon. An appreciation dawned that ECP braking and DP, in an integrated package, sharing the same intra-train communication system, could offer synergy in addressing both sets of problems. The authors examined the emerging radio-based and wireline intra-train communication technologies. Economic stringency reduced the initial temptation, to evaluate both radio-based and wireline systems, to a pilot test of only one candidate. Among other considerations, loss of communication, particularly in tunnels located over crests, seemed risky, so consensus emerged around a wireline pilot scheme. Furthermore, the critical mass in the industry seemed to have developed around wireline. By that time, late 1998, it appeared that at least two suppliers would bid on a wireline system, and the authors therefore recommended to equip a 200-car wireline pilot scheme through open tender. A conservative approach preferred an overlay system, but only to avoid the risk of a train out of service for a technical problem during the assessment period.

An ECP braking and DP pilot scheme

The project was called a pilot scheme, rather than an experiment or test, to connote a positive view on its future. Nevertheless, no further implementation is realistic until it has delivered on the following five objectives:

Assess technical workability of the intra-train communication system alone, ECP braking alone, DP alone, and integrated ECP braking and DP.

Assess the potential to ameliorate quantifiable problems and undesired incidents related to long, heavy train operation, under local conditions, and the economic benefit that might accrue.

Assess alignment among local requirements and AAR Standards, with a view to possibly retrofitting the fleet. In particular, AAR Standards do not define single handle control of both conventional pneumatic- and ECP braking, and 200-car trains require intra-train communication to support more than the 160 cars provided for in AAR Standards.

Assess the potential to open new opportunities by applying information technology to the train-as-system, to integrate trains into the information technology that pervades the freight logistics industry.

Most important, the pilot scheme must deliver a credible strategic recommendation, which will turn smart technology into a robust, profitable solution, because there is currently insufficient service experience within the industry on which to base such a decision.

IMPLEMENTATION PROGRAM

Equipment rollout

The business was awarded to WABCO Railway Electronics, now Wabtec, in March 1999. Four electric lead locomotives, and 208 CCL^{-9} cars, now designated *CCE*, were equipped for ECP braking and DP operation, and fully commissioned by July 2000. Permanent wireline through-cabling and intra-train connections, or temporary through cables with integral connectors, have been provided for a further sixteen locomotives, to facilitate optimum utilization (the locomotives are also used on conventional air braked trains). A two-unit instrumentation car has also been equipped with ECP braking, to permit it to be marshaled anywhere in a test train. The CCE cars operate with conventional air brakes on the trip from Ermelo to the loading sites and return. These cars and locomotives are in captive service.

Technology description

Kull (1999) has fully described the car- and locomotive equipment. It integrates ECP braking and DP in a wireline system, in an iteration beyond that reported by Manconi (1999) regarding Canadian Pacific’s test of ECP braking and DP on the same train. Some distinguishing features are:

ECP braking and conventional air brake integrated into the same handle.

EPIC, ECP braking, and DP setup and operation integrated into a single, color LCD display.

Car control device with repeater functionality, that allows the engineer to designate any car as a repeater for data transmission. Note that the AAR Standard provides for 180 nodes and 12 000 feet, versus the local requirement of 208 nodes and 8 400 feet.

EVALUATION METHODOLOGY

Project design principles

The subject evaluation rests on back-to-back comparison of a 200-car test train equipped with wireline ECP braking plus DP, and a 200-car control train equipped with conventional air brake equipment and head-end power only. The trains were repaired to as near identical standard, and are deployed in as near identical service, as is practicable. This design, which compares the new technologies in a controlled environment, to promote confidence in findings, is comparable to the research design reported by Stauffer (1997). As well as comparing the conventional train with the ECP-braked train, instrumented comparisons of the ECP-braked train, in both ECP braking- and conventional pneumatic mode, will control for train-to-train differences regarding braking performance.

Planned measurements

The authors synthesized the evaluation program from previously reported benefits of ECP braking (McLaughlin, Truglio & Rioux, 1998; Guins, 1998; Stauffer, 1997, 1998), suppliers' claims, articles in the railroad press plus, above all, its own expectations and insights regarding specific pre-existing problems. Assessment will cover at least four consecutive seasons, although a sufficient body of data might accumulate earlier or later, to support a strategic decision one way or the other.

Some systemic benefits, such as shorter cycle time, may not be accurately quantifiable in a pilot scheme, because it is not possible to fully control for the dominant influence of non-pilot-scheme traffic. In the event, it appeared that cycle time may indeed be significantly shortened, and the sequence of tests reported here accelerated such measurements, to get a first cut at economic viability.

The project extracts data that map to existing, quantifiable problems, from four sources. First, project-specific physical measurements that reflect current understanding of speeds, forces, pressures, temperatures, etc. for loaded trains. Second, an operations log, that records items such as movements, tonnages, etc., and follows up each trip with both a structured engineer debriefing and an operations questionnaire. Third, routine reports on the condition of all cars, including those in the test- and control trains, from an integrated train condition monitoring system, located at discrete intervals along the lineside. Fourth, expenditure to maintain items such as brake shoes, drawgear, and wheelsets. These four sources will ultimately support economic and statistical analyses.

Train configuration

A sequence of preliminary tests of longitudinal in-train and train-track forces, undertaken during August 2000, confirmed the decision regarding which train configuration to take forward for extended evaluation, as not being at least better, but never worse, than the existing situation. The selected configuration reflects an operational aversion for locomotives within a train. Table 1 shows its relationships to other configurations that will be tested later.

Placement of six locomotives	**Conventional pneumatic**	**ECP braking only**	**DP only**	**ECP braking plus DP**
Head-end only	**Baseline**	Benchmark against baseline		
2 head-end + 4 mid-train			For ECP braking + DP versus DP-only evaluation	Candidate extended-evaluation configuration
4 head-end + 2 rear-end (or 3 head-end + 3 rear end)			For ECP braking + DP versus DP-only evaluation	**Selected extended-evaluation configuration**
2 head-end, 3 mid-train, + 1 rear-end			For knowledge repository	For knowledge repository

Table 1

PHYSICAL MEASUREMENTS

Longitudinal in-train forces

Measure continuously over entire route, each of the 200-car train- and equipment configurations in Table 1. Examine the distribution of quasi-static coupler forces during steady running, slack-action forces during service and emergency brake applications, and compressive forces during dynamic braking (to be undertaken later).

Longitudinal train-track forces

Locomotive consist placement versus forces applied to track, to examine stability of track structure versus applied force (to be undertaken later). Concrete ties moving relative to the rails and the ballast bed have been experienced locally, seemingly related to high tractive forces under conditions of low overhead line voltage. It was thought to be worst behind rear-end locomotive consists.

ECP braking system performance

Brake cylinder pressure build up time, at first and last cars, to compare ECP- with pneumatic braking (to be undertaken later).

Stopping distance on a 1.52 percent descending grade, at authorized speed ±6mph, for service and emergency applications. Authorized speed is 50mph, except where a lower speed is prescribed to limit thermal loading of cars wheels on long descending grades.

Stopping accuracy: Time to stop at a designated spot, within a ±60 feet tolerance, from 18-, 38-, and 50mph, on various grades (to be undertaken later).

Lateral and vertical wheel-rail forces

Measured with instrumented wheelsets, at selected positions regarded as critical in the train, and **with instrumented track**, at selected positions regarded as critical for the train, during service- and emergency brake applications, and dynamic braking (to be undertaken later).

Train speed regime

Current design speed: Determine baseline speed profile on the train configuration selected for extended evaluation.

Site speed variation (normal): Determine train-to-train speed variance envelope at any particular site at normal speed on a distance base (to be undertaken later).

Site speed variation (abnormal): Plot speed variation envelope at any particular site at abnormal speed (due to restriction, power shortage, defect, or malfunction) on a distance base. Compare with normal site speed variation to assess where, or under what condition, engineers may experience stress or where super elevation may be difficult to maintain (to be undertaken later).

Energy consumption

Calculate baseline values for pneumatic-only train and for ECP-braked/DP train.

Measure actual instantaneous energy consumption rate for all train- and equipment configurations, over entire trip (loaded and empty), and integrate (to be undertaken later).

Identify motoring starts and ends as events, and integrate amount of energy expended on power braking (to be undertaken later).

Wheel temperatures

Measure continuously, using portable thermocouples at four selected wheels per train, and review integrated train condition monitoring system recordings, to assess where to place portable lineside measuring equipment (to be undertaken later).

Measure on all cars at designated sites, selected from among long descending grades and third-order inflections, to examine the temperature distribution among the wheels of a train. Use portable bolometer at sites where high temperatures are expected, and where there is no integrated train condition monitoring system coverage (to be undertaken later).

Wheel wear

Measure wheel tread profile change of a sample, over time, using Miniprof equipment. Baseline condition has been measured.

Electro-magnetic compatibility

Measure electromagnetic interference on wireline (to be undertaken later).

Compatibility with customer environment

Confirm non-interference of loading stations and rotary tipplers with ECP braking equipment. The equipment has been cleared in this regard.

OPERATIONS LOG

Extended evaluation commenced September 2000, with a view to establishing a body of data to support statistical analysis. The following data are recorded:

Movements record

Entire origin-destination cycle, using 100-car blocks as unit of control, including trips to mines for loading and return to Ermelo, the date, train number(s), engineer name(s), distance in miles, number of cars, and gross train tonnage.

Loading site activities, such as car-to-car connector separated or not, and size of block handled (e.g. 25 cars).

Train compositions: For ECP-braked/DP train, running numbers, and position(s) of head-end and rear remote locomotives: For control train, running numbers of head-end locomotives.

Train brake system record

Time to charge, examine, and certify trains, the number and grade of personnel involved, and the value of equipment deployed for preparation at Ermelo and Richards Bay.

Inoperative brakes cut out at departure plus, if applicable the reason—defective slack adjuster/defective control valve/defective car control device/other (specify), delay to train involved and consequential delay to other trains, and cost of rectification.

Pressure gradient and, if applicable, cause of non-compliance, location of occurrence, cost of rectification, delay to train involved, and consequential delay to other trains.

Post-trip *Engineer Debriefing* plus *Event Record*

The engineer's and the operator's view of the same trip, recorded separately, but addressing common items, except where only one view is possible. Together, they record at least date, train number, departure time, engineer name, time(s) and kilometer point(s), car or locomotive running number(s) as the case may be, delay to train involved and consequential delay to other trains, for the incidents described below. Mention is made of additional, specific measurements where appropriate. Certain items in this category measure the presence or absence of stressors, as a surrogate for engineer stress, rather than measuring physiological stress directly, which is difficult to do routinely in an operational environment.

Active locomotive ECP braking equipment malfunction (lead, trail, or remote): Describe malfunction(s).

Car ECP braking equipment malfunction: Describe malfunction(s).

Lead locomotive DP equipment malfunction: Describe malfunction(s).

Remote locomotive DP equipment malfunction: Describe malfunction(s).

Stop to reset locomotive equipment: Specify cause(s) or fault(s), and indicate lead consist/remote consist. If in a remote consist, record how the locomotive(s) was/were reset.

Signal continuity reliability (brake pipe or wireline): Indicate air hose failure/intra-train connector failure/other (specify).

Car air reservoir low pressure warnings: Describe action taken.

Inoperative car brake en route: Record cause if known—defective slack adjuster/defective control valve/defective car control device/other (specify). Indicate whether it was necessary to stop the train to find or rectify the problem.

Stuck car brake en route: Record cause if known—handbrake not released/defective slack adjuster/defective control valve/defective car control device/defective holding brake/other (specify). Indicate whether it was necessary to stop the train to find or rectify the problem.

Deliberate emergency brake application: In each instance, record reason, and whether it caused a derailment or train parting.

Undesired emergency brake application: In each instance, record apparent cause, and whether it caused a derailment or train parting.

Holding brake application: Record reason for use, e.g. signal at danger/other (specify).

Penalty brake application: Record cause of each occurrence.

Untrustworthy brakes: Record instances, where the engineer stopped further from a red signal/flag than he/she intended, and describe the circumstances.

Train parting: Record position(s) in train, cause if known (e.g. low speed/high tractive effort, unstable line voltage, wheelslip indication, etc.), failed component, and whether train derailed. Examine failed components metallurgically for prior- or other defect.

Critical signals on ascending grades, during regular working: Record instances where the train was held back to avoid stopping at a critical signal on a following ascending grade (a critical signal is one where there is high probability of parting a train when attempting to lift it).

Critical signals on ascending grades, during irregular working: Record instances where engineer did not respect critical signals, record the reason, and describe the consequences.

Undesirable stops on descending grades: Record instances where the train was held back to avoid using the holding brake on a following descending grade (applying the holding brake, recharging the automatic air brake, and releasing the holding brake, requires ± 45 minutes).

Any other unexpected/unexplained/undesired occurrence? Record details.

Items for *Engineer Debriefing* only

Power braking on descending grade inflections: Record instances in which the engineer applied power against the automatic air brake to avoid stalling, the brake pipe reduction, and the speed range.

Over speeding on descending grade inflections: Record instances where it was necessary to exceed design speed, to avoid stalling because there was insufficient time to recharge the automatic air brake, the brake pipe reduction, and the speed range.

Use of engineer skills to manage ambiguity (e.g. stalling train): Record instances where the engineer had to choose between two or more actions, neither of which was recommended or authorized, and the reason.

Use of engineer skills to overcome equipment shortcomings: Record instances in which the engineer could not follow best practice due to equipment condition or equipment limitations, and the reason.

Use of engineer discretion in unfamiliar situations: Record deviations from design speed profile, such as temporary speed restrictions for maintenance occupations or high-rail-temperature, low overhead line voltage, wheelslip/-slide during rain, and/or any other (specify).

Items for *Event Record* only

Extraneous delays: Record reason(s).

Derailed train: Record cause, e.g. train parting, wheel defect, roller bearing damage, other (specify), and cost.

ROUTINE REPLACEMENTS DURING CAR MAINTENANCE

Data acquisition

An SAP module records all maintenance data per car running number, using unique designations—*CCE* for ECP-braked cars, and *CCP* for control cars.

Brake shoes

Record car running number, date fitted, number of shoes replaced, cost to replace, and weight of used shoes.

Procedure: ECP-braked- and control trains were fitted with new shoes at the start of extended evaluation. Both trains will run until general replacement is required. All shoes will be removed simultaneously and then weighed, keeping car sets of shoes together. Individual high-wear outliers may be replaced as required and recorded separately. Replacement will only to be done during four-monthly inspections.

Wheels

Record car number, date, number of wheels replaced, cost to replace, and reason e.g. skidded, spread rim, flange wear, hollow wear, cracked, other (specify).

Bearings, brake control equipment, brake rigging equipment, coupling elements, holding brake equipment

Record car number, date, quantity- and description of components replaced, cost to replace, and reason.

ROUTINE REPLACEMENTS DURING LOCOMOTIVE MAINTENANCE

Data acquisition

An SAP module records all maintenance data per locomotive running number.

Relevant equipment

Record cost to replace knuckles and drawgears (coupler bodies and yokes are seldom replaced).

Record cost of maintaining holding brake equipment.

ROUTINE TRACK MAINTENANCE

Some systemic costs, such as routine track maintenance, are not quantifiable in a pilot scheme, because one can not control for the influence of non-pilot-scheme traffic. Nevertheless, there is an awareness of sites where longitudinal track disturbance is associated with high tractive effort. Such disturbances may influence the parameters within which locomotive consists are placed in DP trains. The intent is therefore to monitor such sites regularly.

CONTROL VARIABLES

Purpose

The following control variables may or may not influence relevant variables. However, one needs to monitor them to ensure confident and reliable interpretation of measurements of relevant variables.

Brake pipe flow rate

Measure at monthly intervals, to monitor air tightness of the trains.

Wheel surface damage

Record presence of damage other than flats, to give an inventory per car.

Integrated train condition monitoring system

Purpose: The integrated train condition monitoring system identifies and records car- and train numbers, plus the following variables, in a database that uses car or locomotive as object.

Car weight, selectable from total tons per truck or total tons per car side.

Wheel temperature, measured per wheel at two sites, one where brakes should be released and cold (it looks for hotter wheels) and another where brakes should be applied and hot (it looks for colder wheels).

Bearing temperature, per wheel, measured by hot box detectors at seven sites.

Wheel flats: output is an impact force.

Wheelset lateral force, moment in ton-feet, for each truck. It identifies skew trucks and crabbing locomotives, for loaded trains only.

FINDINGS

Early impressions

No surprises, so far. Although most of the evaluation still lies ahead, the initial exposure to ECP braking has confirmed experience reported by other railroads.

Integrated ECP- and conventional pneumatic braking in a single handle is so intuitively obvious that additional training in this regard is unnecessary. Note that the automatic- and independent brake handle movement has been reversed (pull to apply), to respect traditional South African practice.

Graduated release promotes optimum use of dynamic braking. During training, engineers intuitively gave preference to dynamic braking and varied the total braking effort by modulating the ECP brake. It is encouraging to find intuitive preference for recommended practice, because supervisors may rest assured that engineers will not deviate from it. In addition measurements of brake cylinder pressure on the test car, immediately behind the leading locomotive consist, indicated lower average pressures throughout the run compared to pneumatic operation. The smaller brake applications required reflect more even and fast response throughout the train, as well as optimum use of dynamic braking.

Lower skill requirements: The current 200-car trains require continual awareness of the state of the train and in-train forces, particularly when traversing certain crests, where the engineer relies on an accelerometer to keep forces within safe limits. This level of skill tends to shrink the pool of candidate engineers, whereas ECP braking and DP enlarges the pool that offers suitable skills.

Apprehension among some engineers: The current 200-car trains reputedly stress engineers more than other trains. However, a physiological study by Hanekom (1997) found their stress levels to be no higher than when driving other trains or on days off duty. It is nevertheless difficult to distinguish stress from other hygiene issues that pervade a unionized environment. There is therefore still advantage in reducing stress. Although some engineers were initially apprehensive about a new technology, their experience is that graduated release ECP braking and DP eliminate train-related stressors.

Adaptation to an information technology environment: South Africa currently has few locomotives with computer display screens. During initial training, it became apparent that some of the engineers were outside their comfort zone. Contracts have however been entered into for upgrading the heavy haul locomotives, which will make such man-machine interfaces the norm.

Electromagnetic interference from overhead electrification equipment. Both South African heavy haul lines are electrified, hence considerable care needs to be taken to restrict voltage induced in cables to less than the legal maximum of 50V, relative to earth. The severity of the problem will depend on the type and frequency of the supply, and the length and configuration of the cars and train. Lineside fencing or shielded signal cables typically require each individual wire section parallel to the overhead power supply to be less than 5000 feet. The wireline on the CCE cars is shielded and runs in a 1-inch pipe conduit under the belly, to provide maximum shielding from electromagnetic radiation and induced voltages. All personnel involved have been trained to assume that the wireline cable is live at all times when cars are coupled into a train, even when no locomotive is attached. There is suspicion that sporadic emergency brake applications may be due to electromagnetic interference, and an investigation is under way. Induced voltage thus remains an issue for wireline ECP braking/DP on all electrified railroads.

Software development

Final software is not yet in place, but the version in use is robust and easy to use. Field experience will indicate what changes are needed.

Formal measurements

Shorter stopping distances give engineers confidence in approaching lineside signals and prescribed descending grade speeds much faster than with a conventional pneumatic brake. Initial results imply similar stopping distances for a fifty percent higher initial speed, or distances of between a third and a half of conventional trains. Typical stopping distances from 28mph on a 1.52% descending grade were, for conventional pneumatic braking ± 4600 feet, for conventional pneumatic braking plus wireline DP ± 3000 feet, and for ECP braking ± 1500 feet. Engineers are able to stop precisely where desired, and not where the train determines. Stopping distance tests have proved easier to perform, as ECP braking allowed initiating the test from exactly the intended speed. Previous tests on descending grades, targeted for 28mph, started anywhere between 20- and 30mph, due to the difficulty of controlling speed accurately over varying grades with direct release brakes.

Smoother train action: Stopping an ECP-braked train with a full service application is deceptive, due to the absence of longitudinal train action. Despite the significantly shorter stopping distance, the engineer's initial reaction is that the train is not slowing as rapidly as usual. Deceleration of 40mph/minute has been observed on a 1.52-percent descending grade with a loaded train. The authors expect that derailments following emergency brake applications with conventional air brakes, particularly with empty trains, will become history. Somewhat unsettling was the discovery of surges in the middle of a loaded train, during a full service pneumatic stop, of up to 110 000lb buff. This was not experienced with ECP braking.

Lower in-train forces: The full series of in-train force tests has not yet been completed, as the in-train measuring stations have only recently been commissioned. Nevertheless, indications are that maximum tractive effort is reduced from around 400 000lb to 240 000lb with distributed power.

Generally lower train-track forces: Comparative tests were performed on three train configurations, namely:

Head end power, four Class 11E locomotives, 200 cars weighing 22 900 tons.
Head end power, five Class 7E1 locomotives plus 200 cars weighing 20 300 tons.
Distributed power, four Class 7E1 locomotives at head end, plus 200 cars weighing 22 900 tons, two Class 7E1 locomotives at rear end.

Two critical situations exist, where either maximum traction or dynamic braking are exerted in curves, and two test sites were chosen where track forces are known to be high. Vertical loading, lateral forces, movement of the rail and ties, tie stresses and longitudinal rail stresses were measured. The differential stress (compressive to tensile) under the locomotives was 28 000lb for the Class 11Es, compared to 16 000lb for the Class 7E1 head end and DP trains. In general the tests suggested that DP may reduce track forces, as the DP train forces were similar to those of the lighter Class 7E1 head end powered train, rather than those of the Class 11E train. Evidence to suggest that the higher speeds may increase track damage has however also been found. Previous work (Van der Meulen, 1991) regarding relations among speed, energy consumption and track damage suggests that a systemic approach to the issue would be appropriate.

Lower car wheel temperatures: As measured by the integrated train condition monitoring system, the average and standard deviation were respectively 236^{o}F and 91^{o}F for the conventionally-braked control train, and respectively 222^{o}F and 69^{o}F for the ECP-braked train. This despite speed being increased from 28mph to 31mph on long descending grades. These values indicate that ECP braking reduces both thermal input into car wheels and car-to-car temperature variance. The lower standard deviation with ECP braking could be significant in reducing occasional thermal peaks that lead to catastrophic wheel failure.

ECP braking shortens cycle time. First, the running time of a conventional pneumatic brake train is 17 ½ hours. Tested against the same criteria, the running time of the ECP-braked train is 14 ¾ hours, saving 2 ¾ hours out of a total cycle time of 60 hours. Much of this saving results from ten percent higher downgrade speeds, due to the full use of dynamic brake plus even wheel heating, plus the ability to run at the permitted maximum speed at all times, without concern for brake application- and recharge times. Second, and not included above, is an estimated 30 minutes per trip, over and above the running time, that it takes to restart from several signal stops en route, due to recharging and train handling with direct release brakes. Third, should the holding brake be applied when a train is stopped on the ruling descending grade, it takes approximately 45 minutes before it can depart. Graduated release renders the holding brake unnecessary. Fourth, new brake-test procedures can save time—see the following paragraph.

Organizational learning

Separation of testing for continuity and examination of car brake mechanical condition: Currently a traditional “A” test (local terminology) is applicable, to check both brake pipe continuity and mechanical condition—i.e. do the brakes apply and release on all cars—at the start of a trip. They contribute nearly three hours in a total cycle time of around 60 hours. The rate of degradation of mechanical equipment (pneumatics, slack adjusters, rigging, and shoes) is however much slower than the train cycle time, therefore mechanical condition could be inspected less frequently than once-per-trip. Currently, the mechanical condition is determined in a drive-by examination, rather than by walking the train. The effectiveness of such an inspection is open to question. One nevertheless ought to confirm continuity at every departure, a functionality that ECP braking inherently supports. The pilot scheme will pursue separation of these functions in conjunction with integrated train condition monitoring system reports, with a view to shortening cycle time.

Maintenance: Managers close to the operation have now had exposure to the reality of information technology potentially displacing a familiar, though imperfect, pneumatic world. Their trepidation is unmistakable. This issue will require empathy when contemplating a fleet conversion to ECP braking. The experience thus far suggests that electronic equipment will be more reliable than conventional pneumatic equipment.

Vandalism: South Africa suffers from theft of anything that contains a battery, or metal with attractive scrap value, such as copper or aluminum. The CCD and car ID units are stacked on a bracket on the car ends, both protected by a hinged cover, fastened with security bolts. Thus far, a cable from the CCD to the manifold on one car has been found cut, and the insulation neatly stripped to determine the metal used. In addition, one CCD was found with all four supporting bolts removed. It is not possible to remove the unit from under the cover, and an attempt was therefore also made to remove one of the security bolts. Fortunately, no further vandalism was experienced.

Pro overlay: Several experiences during commissioning vindicated the choice of an overlay system. Operations can simply not afford to have pure ECP-braked cars idle. It has proven difficult to get all 208 cars equipped and commissioned simultaneously. There have been times when some of them have been used in pure pneumatic trains.

Furthermore, during initial commissioning there was one incident that required the train to run in pneumatic mode to clear a single line section and proceed to the next siding where ECP braking was set up again. Nevertheless, the authors share the industry’s perceived preference for stand-alone ECP braking, probably with a pneumatic emergency portion. Since the first 200-car run on June 28, the train has worked a 520-mile, two-day, round-trip cycle without problems and without needing to revert to pneumatic mode. During the first week of September, the train reverted to pneumatic mode because the locomotives were required for intensive engineer training, after which ECP braking plus DP operation resumed.

Con overlay: Aside from the obvious cost disadvantage, an overlay system still needs empty-load equipment to prevent skidded wheels during a pneumatic emergency brake application. Although the coal cars are being retrofitted with L-1 detectors, the cars used for the ECP braking project are refurbished older cars, and a decision was taken not to fit load weighing to those cars that did not yet have it. A portion of the cars’ cycle will require them to operate with conventional pneumatic brakes, hence the risk of skidded wheels remains. This could influence measured results.

Possible automation: In a previous paper, the authors (1998) reported on exploring the bounds of informationalized train handling, as a precursor to the present pilot scheme. From experience gained recently, automation now seems much less attractive. With integrated ECP braking and DP, train handling undergoes a paradigm shift, becoming so intuitive that engineer skills may go the way of many other Industrial Age skills.

Reduce brake ratio: Given the suspicion that high brake ratios contribute to derailments during emergency braking, the authors are contemplating reducing high brake ratios, without lengthening stopping distances. There is however still a need first to calibrate brake force percentages displayed by the HEU against the brake pipe reductions customarily used on long descending grades.

Repeater software: Due to the limitations of the current AAR-standard transceiver, and the specified maximum number of nodes, it is not possible to use the standard system for more than about 180 cars. The pilot scheme therefore makes use of a software repeater function, to reach the required train length. Any car, approximately in the middle of the train, is designated as a repeater from the leading locomotive during setup. This car rebroadcasts the messages it receives, in order to bypass the transceiver limitations. Although this accommodates longer trains, it adds significantly to bus traffic. Although a next-generation system would allow the train to run without the repeater, the concept is functional and usable.

Use of an end-of-train device (EOT): Although the AAR specifies the use of an EOT, the authors’ experience so far is that it is of questionable value on unit trains. Where the train composition changes, as with general freight, it reliably ensures completeness of the train. With sequencing, or a remote locomotive at the rear end of a train, the authors would prefer a software EOT function. The EOT is vulnerable to vandalism, and has been the source of most problems during August 2000. The question of an EOT on an ECP-braked train needs to be revisited.

FUTURE ECP BRAKING AND DP OPTIONS

Fleet retrofit

Subject to the pilot scheme demonstrating clear economic advantage, from either ECP braking or DP separately, or from both as a package, the current intent is to retrofit a fleet of at least 6500 cars and up to 100 locomotives. DP alone has already justified itself economically, primarily by virtue of reduced track- and drawgear damage due to high tractive forces. Preliminary indications are that ECP braking could justify its incremental cost over DP alone by virtue of cycle time reduction and reduced derailment risk.

Radio-based DP?

The alternative of radio-based DP remains attractive for non-coal cars without wireline on the Ermelo-Richards Bay operation. This attraction does however need to be weighed against the complexity and risk of operating two types of distributed power with significantly different performance characteristics.

General freight service?

The authors are not contemplating extending ECP braking to general freight service, where there is still a struggle to convert vacuum brakes to air brakes. The present pilot scheme is thus predicated solely on examining the advantages of wireline ECP braking and DP in captive service. The authors do not presume to offer insight on how to extend ECP braking beyond that, nor do they exclude the possibility of such extension. There nevertheless exists a potential internal market for hand-me-down ABD, ABDW, ABDX, and DB60 control valves, namely the vacuum-braked cars that still need conversion to air brakes in South Africa. Its ECP braking economics could thus be more favorable than those of other railroads.

CONCLUSIONS

Perfecting the heavy haul train

The authors have found integrated ECP braking and DP to be much more than the sum of its parts. The new technology makes an assemblage of cars and locomotives come alive in the hands of an engineer. It is not customary to employ superlatives in scientific works, but without doubt ECP braking and DP offer a quantum leap in railroad competitiveness. The authors no longer support an *either* ECP braking *or* DP approach—for heavy haul the real value resides in their integration.

Prospects …

The economic viability of ECP braking within the global railroad industry is not yet firmly established. In addition to the measurable benefits already mentioned, the following valuable, systemic benefits also accrue:

- Promote a paradigm shift.
- Reconfigure a railroad system for higher output-function maximum.
- Simplify equipment/reduce capital cost.
- Enhance line capacity.
- Speed-up brake testing.
- Improve train handling.
- Monitor trains for abnormal conditions.
- Optimize maintenance.
- Manage human stress.
- Enhance rail system predictability.
- Enhance system flexibility.

Although these benefits feature in the evaluation program, the authors can not isolate them from contamination by non-pilot-scheme traffic with sufficient rigor. They must therefore await analytical evaluation at a later stage, to serve as input to the judgmental component of the investment decision. As such, they take on the role of qualitative drivers.

In captive unit train service, it is appropriate to question the need for a CCD on each car and the value of an overlay system. Routine car maintenance on the Ermelo-Richards Bay operation is in process of being converted to a drawbar-coupled four-pack basis. The lower capital cost implications of a single CCD per four-pack could be compelling, and could significantly enhance the attractiveness of ECP braking.

… and risks

The authors have presented full insight into the quantifiable drivers of the Ermelo-Richards Bay pilot scheme rationale, to stimulate the industry to examine ECP braking at the most comprehensive level of analysis. The issues go beyond the simple desire for a better brake system. If the technology proves successful, and there is every expectation that it will, few railroads will be able to muster as good an economic case. However, it is the authors' perception that if this economic case does not result in fleet conversion, the prospect for ECP braking on other properties may wane. Furthermore, it is desirable that a critical mass of support emerges in the industry, to reassure decision-makers that such investment will be sound—or else its implementation may be at risk. The wireline ECP braking (and complementary DP) question thus seems poised on a knife-edge at this time.

ACKNOWLEDGEMENTS

The authors recognize the major contribution of Spoornetters and suppliers, who worked countless hours to get ECP braking and DP up and running.

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