Development of Train Handling Techniques for 200 Car Trains on the Ermelo-Richards Bay Line

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1 INTRODUCTION

Trailing loads at commissioning of the Ermelo-Richards Bay line in 1976 were 76 cars loaded to 74 tonnes gross, hauled by six class 34 diesel locomotives. Soon thereafter the line was electrified at 25 kV AC, and the loads ultimately increased to 88 cars, at 80 tonnes gross, hauled by four class 7E locomotives. Pertinent features of these and other locomotives mentioned in this paper are listed in Appendix 1. On 1,52 % ascending grades coupler force and power demand were approaching values which at the time were considered limiting. The original scheme was by then fully extended, particularly in respect of passing loop lengths. However, traffic forecasts indicated that an upgraded scheme to increase line capacity would be required. Substantially higher loads were thought to be necessary, and the train handling implications of such higher loads were therefore investigated. The rugged topography in particular demanded very careful evaluation of options. It was also considered desirable that drivers should not perceive the complexity of their task to have increased significantly, despite much higher loads being contemplated. Technical parameters and human interfaces had therefore to be planned accordingly. The paper reports on the route by which these objectives were realised. The next section discusses aspects which influenced conceptualisation of the upgraded scheme.

2 PRELIMINARY PREFERENCES AND CONSIDERATIONS

2.1 Driving Feel

During operation of the original scheme it was perceived that various factors limited its potential in terms of train length and tonnage. Many of these related to the response of a train to topography and to the choice of design parameters, and hence its feel in the drivers hands. At first glance this might have been attributed to unfamiliarity with heavy trains. Whilst the drivers obviously had to progress along a learning curve, it was nevertheless noted that handling difficulties did not always relate rationally to parameters which were measurable or even considered important. The author ultimately took to driving personally, in order to experience first hand which parameters are relevant, how they interrelate and how a driver plans his task. It was in the end possible to design train handling characteristics so as to give a driver confidence in his task. It was found that refining the feel substantially extended his perception of his ability, without increasing the skill required. No startling discoveries were made, other than that feel is often equal in importance to theoretical analysis and technical judgement. Obviously physical limitations must be respected, but within these limitations drivers' requirements and perceptions are of critical importance. The ability to acquire accurate data on in-train phenomena and the understanding of train handling feel enabled a freer driving style to be developed and to be transferred to drivers during advanced training.

2.2 Train Length

It was considered that train length with a single feed valve should not exceed about 200 cars, because response of AAR direct release brakes degrades too much beyond this value. Nevertheless, it was economically attractive to maximize train length within this constraint. Experience with trains in excess of 200 cars on the topographically easier Sishen-Saldanha line suggested aspects for attention when contemplating similar trains on the Ermelo-Richards Bay line. Trains of 230 cars, many of which have ABD control valves, subjectively feel at the limit of response on the Sishen-Saldanha line, and accelerated application valves were therefore considered essential on more rugged terrain. Provided that train action forces can be contained within acceptable limits, longer trains are preferred because they average grades over a greater distance, and so give drivers more time to plan their handling. It was therefore judgementally concluded that 200 car trains were both feasible and practical.

2.3 Control of Train Action

The first generation 80 ton CCL-1/3 cars on the Ermelo-Richards Bay line have conventional couplers at each end of each car. With 88 cars, train action proved fully controllable, but there were indications that proportionately more slack would be cumbersome on trains of more than twice this length. By contrast, the Sishen-Saldanha line was the first in South Africa to employ bar couplers between pairs of cars. These offer a good compromise between providing sufficient slack for picking up trains, and reducing slack to control harsh train action. It was therefore decided that the 104 ton CCL-5/7 cars should be made up in semi-permanent pairs with bar couplers. The only difference between CCL-5 and CCL-7 cars is that the latter have a strengthened coupler shank and pin. Lineside signals have been divided into two categories - difficult and critical. Difficult signals are those where a driver may under prescribed circumstances attempt to pick up a train. Critical signals are those where a driver is by rule prohibited from attempting to pick up a train under any circumstances. Practical experience with the efficacious wheelslip control system of the class 7E locomotives had however demonstrated that picking up heavy loads on ascending grades was comparatively easy. Notwithstanding the rule, drivers sometimes did stretch the capability of these locomotives by picking up trains at critical signals. This practice can easily induce extremely high dynamic forces, and it has been very strongly discouraged on 200 car trains in order to limit coupler force to that which F-type couplers
can accommodate.

2.4 Feeder Loads

Running 200 car 20 000 tonne trains from Ermelo requires 100 car 10 000 tonne feeder loads from the mines. This arrangement complements their loadout capability, and facilitates marshalling at Ermelo. Trains of 200 cars from Ermelo were in principle only acceptable on condition that such simple feeder loads could be worked. Although ruling grades against feeder loads are only 1,0 %, this is a very heavy load on a 3000 V DC line, demanding an overhead supply current of up to 6000 A. Test trains were run with a consist of six class 6E1 electric locomotives. The loads handled acceptably, despite resistance control, pure regenerative electric braking and a rudimentary wheelslip correction system. Subsequently, when the hi-tech chopper controlled class 10E locomotive became available, it was allocated to this duty. Its power control system is gentle on both train action and overhead power supply stability. Four in multiple haul 100 car feeder loads. It has a generously rated extended range dynamic brake, and is thus suited to heavy haul service.

2.5 Experience with In-Train Locomotive Consists

Radio remote-controlled locomotives had at one stage been considered as a means to increase line capacity from Ermelo to Richards Bay. Extensive tests simulated such operation using 160 car trains employing two equal sized consists of six diesel locomotives each. The automatic brake was controlled from the lead locomotive only. The second consist was manned, and a voice radio link was provided between the two consists. In order to move the zero coupler force node to a position ahead of the second consist, the latter was positioned approximately two thirds back in the train (Parker, 1974). Combinations of 100 + 60 and 110 + 50 cars were tried. Instrumentation to measure train action phenomena was not available at the time, but subjective judgement favoured the 110 + 50 car combination, which placed the node nominally 30 cars ahead of the second consist. These tests demonstrated that independently controlled in-train locomotive consists were compatible with the rugged terrain. Although not objectives at the time, it was nevertheless established that voice radio could satisfactorily coordinate two drivers, and suggested that 200 car trains would be feasible. This scheme was unattractive because unequal length feeder loads impair logistical efficiency, and was not pursued further. However, the fortuitous experience laid the foundation for the double length trains described later.

2.6 Imbalanced Ascending and Descending Grades

Preliminary analysis indicated that an extreme imbalance between ascending and descending ruling grades should be contemplated. It was also economically attractive to flatten only ruling ascending grades against loaded trains. The imbalance between ruling 0,4 % ascending and 1,0 % descending grades on the Sishen-Saldanha line renders it impossible to hold a train by means of the locomotive independent brake only after release of the automatic brake on a ruling descending grade. However, on that line the relationship between rolling resistance, grade component and dynamic brake rating is such that the automatic brake can be adequately recharged before subsequent applications. On that line signals are also spaced far apart and it is seldom necessary to initiate a brake application shortly after the previous release. On the Ermelo-Richards Bay line, 1,52 % descending grades accelerate a 200 car train against full dynamic braking to authorized speed before the automatic brake can be adequately recharged. Line-side signals are tightly spaced, and an automatic brake application is frequently needed soon after a release. It was therefore necessary to provide a holding brake to hold the train stationary whilst recharging the automatic brake. Having accepted that a holding brake would be provided, long descending grades posed special braking problems. The critical contribution of good braking to acceptable train handling and the design of the braking package to provide it, have been described elsewhere (Van der Meulen and Lombard, 1988).

3 DESIGN OPTIMIZATION

3.1 Optimization Criteria

Class 7E locomotives were ultimately loaded to 26 % nominal adhesion on 88 car trains. It is prudent however to respect the naturally sustainable level of adhesion on a particular line, and there was evidence to suggest that this was often less than 26 % in weather conditions prevailing on the Ermelo-Richards Bay line. Wheelslip or its correction can substantially increase longitudinal dynamic loading when exerting high tractive efforts. It was therefore decided to limit the adhesion demanded by the locomotives of 200 car trains to 24-25 %, so as to reduce the dynamic disturbances on much heavier trains. Quasi-static coupler forces in the range 1500-1600 kN were judgementally deemed necessary to achieve economical ruling ascending grades. A simple locomotive configuration was also sought. The coupler force/ruling grade/driving wheel adhesion/locomotive configuration package for the required trailing load was optimized graphically, as in Fig. 1. This shows that options were limited, and that the package ultimately selected is indeed the optimum. It also clearly shows why the class 7E locomotive was sub-optimum, why a 26 tonne/axle locomotive was also sub-optimum, and why the most economic solution required a new locomotive design, the class 11E.

It was realized that only small dynamic forces could be accepted on top of such high quasi-static coupler forces on long ascending grades. Knuckles and yokes had failed previously at forces around 2300 kN. When hauling 88 car trains with class 7E locomotives, quasi-static coupler forces of around 1200 kN were exerted, implying that failure was caused by dynamic augments of 90 %. When increasing quasi-static coupler forces to 1500-1600 kN, the dynamic augment would have to be less than 50 %. Better information on train action, plus advanced driver training to high standards was thus required.

3.2 The Train Dynamics Instrumentation Vehicle

The train dynamics instrumentation vehicle shown in Fig. 2 measures, processes and displays, in real time, train dynamics phenomena transmitted from outstations at five selected locations in trains up to 3 km long. The vehicle is marshalled immediately behind the leading locomotive consist. It employs a digital telemetry system using a single fibre optic cable. Up to five variables may be monitored at each outstation. They are typically selected from coupler force, drawgear or slack displacement, carbody acceleration and brake system pressures. Each channel is sampled at 200 samples per second. Fifteen additional local channels, typically track grade, locomotive control manipulation and head end values of outstation variables, may also be monitored. Time frame recordings can be triggered when the value or rate of change of selected channels exceeds preset limits, so that the circumstances which caused the trigger condition may be studied. These recordings span 95 seconds, apportioned as required between history and future data. Hard copy is output automatically after the occurrence, for review whilst the circumstances are fresh in the crew's memory. CRTs display the train moving on the line profile, plus the most recent ten seconds' history from up to eight selected channels in strip chart form, in the instrument room and to the driver in his cab. A train may thus be driven with real time information on relevant phenomena displayed to the driver. This facility was used to accurately assess train action phenomena, and then to train drivers to handle critical situations.

3.3 The Final Package

After all the foregoing inputs had been assessed, it was concluded that it would be feasible to work 200 car trains on the Ermelo-Richards Bay line. The trailing load would be 20800 tonnes, hauled by four class 11E locomotives. The rest of this paper reports on stage-wise implementation of these trains.

4 INTERMEDIATE STAGES

4.1 Introduction of Double Length Trains

Together with the design for 200 car trains, permissible car axle load was raised to 26 tonnes. This necessitated relaying the track to higher standards, from the formation upwards. Whilst deviations to flatten ascending grades from the original 1,52 % to the new 0,625 % could be completed before cutting in, relaying was done whilst running a full capacity service. The earlier fortuitous experience with in-train locomotives was recalled and exploited. It was decided to work double length trains temporarily, to drastically curtail their number and so provide adequately long occupations for relaying. The trains were marshalled in the order lead consist, first feeder load, middle consist, second feeder load. Lengths were between 136 and 176 cars, depending on tonnage of individual cars, giving trailing loads of around 14100 tonnes.

4.1.1 Technical considerations

The availability of heavier class 7E electric locomotives at that time made possible what was elusive with the diesel locomotives used during earlier 160 car train tests. Equal length feeder loads were still strongly preferred. Because the double length train could be hauled by only eight class 7E locomotives, a zero coupler force node ahead of a middle consist could be provided by the expedient of using equal blocks of cars, but putting three locomotives in the lead consist and five in the middle consist. The lead driver was solely responsible for automatic brake control and observance of lineside signals, primarily responsible for dynamic braking and secondarily responsible for traction. The middle driver was primarily responsible for traction and secondarily responsible for dynamic braking. Coordination was by voice radio. Later, as CCL-5/7 cars and subsequently class 11E locomotives became available, they were also used for these trains. It was necessary at that time to change to feeder loads of approximately equal tonnage. CCL-1/3 cars were retained in blocks of 88, whilst the new CCL-5/7 cars were formed into blocks of 68. Class 11E locomotives, which have extended range dynamic braking, were permitted in the lead consist only. This avoided stretching the front half of the train at low speeds, which would occur if they followed a class 7E lead consist with standard dynamic braking. Two class 11E locomotives substituted for three class 7E locomotives in the lead consist. Depending on actual train composition, the zero coupler force node was nominally 17 to 25 cars ahead of the middle consist. Due to distorted load sharing between consists, this node frequently moved further ahead. Whilst short of the 30 car ideal established from └ earlier tests, reliability was satisfactory.

4.1.2 Practical problems

The 24 MW aggregate rating of eight class 7E locomotives exceeds the 15,6 MW rating of the four class 11E locomotives designed to haul 20800 tonne trains on the new 0,625 % deviations. It was thus necessary to avoid tripping substations and to control maximum power demand of double length trains by operating the lead consist in half bridge, and by restricting power notches on the second consist. This frequently reduced speed on ascending grades to less than 20 km/h. When operating two independent consists at around half their normal balancing speed, tractive efforts could rise above customary values. On dry, clean rail, adhesion well over 30 % is sustainable without slip, which lets distorted load sharing between consists pass unnoticed. Drivers reacted to the perceived increased risk of coupler failure behind the lead consist at low speed by transferring some of their load to the second consist. There the risk of failure was smaller, be└ cause part of the load was pushed. This aberration causes high longitudinal forces to be applied to the track structure under the second consist and increases thermal loading on its traction motors.

A second major problem encountered was that energy consumption was abnormally high. It was necessary to operate the consists independently to avoid breaking trains, but in certain situations one consist could be motoring while the other was in dynamic braking. Clearly this can not occur with conventional head end locomotive consists only. Double length trains were a stopgap measure to provide occupation time, but were sub-optimum in many respects. It was thus desirable to revert to head end locomotives and conventional handling techniques at the earliest opportunity.

4.2 Pusher Operation

During 200 car train tests before the 0,625 % deviations were complete, class 11E lead consists were assisted by class 37 rear pusher consists. Train handling was conventional except on long ascending grades. After all class 11E locomotives were commissioned, it was decided to exploit the advantages of pusher operation. One advantage was that drivers could reorientate themselves to conventional train handling in preparation for the 200 car trains. Others were that energy consumption was reduced, that faulty locomotives could be readily removed from a train and that crew size could be reduced. Ultimately these trains had a driver and assistant on the lead consist, a driver only on the pusher consist, and a telemeter on the rear coupler to prove brake system integrity.

Pusher trains conveyed the same tonnages as double length trains, but used three class 11E locomotives in the lead consist. A pusher consist of four class 7E locomotives was initially provided over the full distance from Ermelo to Richards Bay. Control of the train was entirely from the lead consist, except at incomplete deviations, where the train was assisted by the rear pusher locomotives over the 1,52 % ascending grades of the old line. At this stage all the cars were not yet fitted with holding brakes, and the rear consist was also required to assist with independent braking when the train was halted on grades steeper than approximately 0,8 %. By November 1988 sufficient cars had holding brakes to make up all head end feeder load so fitted. This rendered pusher Locomotives dispensable except where required for traction, at only two locations between Mahulumbe and Sikame and between eQwasha and uLoliwe. Pusher consists of four class 7E locomotives assisted as required and then shuttled back for the next train. Loads were still restricted to combinations totalling around 14000 tonnes by substation capacity.

Drivers regarded double length train handling techniques as somewhat bastardized, because two persons shared responsibility. They welcomed pusher trains as they restored responsibility conventionally to one person. Undivided responsibility generally refined train handling, and avoided one consist motoring whilst the other was braking. Although speed was simultaneously increased to 80 km/h through dips to exploit momentum, energy savings of around 40 % were realized, as shown in Fig. 3.

5 FINAL STAGE

5.1 Preliminary Tests

Several 200 car trains were tested prior to completion of the new deviations, in preparation for revenue service. These tests used diesel rear pusher locomotives, because the overhead supply was inadequate to power 21000 tonnes on 1,52 % grades with electric locomotives only. These tests proved fortuitous when the final completion dates for the deviations were known. All relaying and deviations were complete by end 1988, except the locations mentioned in par. 4.2, where unforeseen rock formations had postponed completion dates to respectively September and June 1989. Because the economics of 200 car trains are so advantageous, it was decided to introduce full 200 car operation early in 1989, but assist trains over the old line at these locations until the new tunnels are complete. Six class 37 diesel locomotives assist four class 11E locomotives in the lead consist. Mixed diesel and electric working is problem free, and represents an interesting application of diesel power for peak lopping.

5.2 Driver Training

5.2.1 Basic philosophy

Extensive advanced driver training has taught that rational train handling is founded on sound theory plus information on critical phenomena in trains. Drivers also discuss and agree on train handling techniques, whereafter they virtually freeze them. This is a powerful training aid when the techniques are sound and well informed. Drivers distrust aids which occasionally disagree with their experience. They are unable to distinguish exact from approximate algorithms, and consequently distrust aids whose fidelity is suspect. This was observed with an early train dynamics analyser, which although essentially sound, nevertheless occasionally disagreed with practice. For these reasons it was decided to inform 200 car train drivers of critical phenomena in their trains during training. The required information was obtained via the train dynamics instrumentation vehicle. A simplified instrumentation format was used, acquiring data from midpoints of front and rear feeder loads only, plus local head end channels. The measured variables were displayed to the trainee driver on a CRT in his cab, as shown in Fig. 4. This is a valuable training aid because the information is always true and credible. The technique is complex and therefore expensive, suitable only for advanced training. It is compatible with heavy haul service, where a smaller number of heavy trains replaces a larger number of lighter trains. The number of drivers is therefore relatively small, permitting more comprehensive attention to each. Drivers trained in this manner are therefore highly accomplished.

5.2.2 Practical heavy haul training

The abovementioned system has the disadvantage that bungled situations cannot be repeated and refined within a short time, as with a simulator. However, the train dynamics algorithm is exact and the fidelity therefore absolute. The repeatability drawback is countered by cascade training. A Superintendent (Train Dynamics) firstly roughs out techniques on two trips, accompanied by the local Inspector. The latter then drives on two trips, accompanied by an instructor driver. Next the instructor driver drives on two trips, accompanied by his first trainee. Thereafter the procedure repeats until the instructor driver has trained the required number of drivers. Each trainee is thereby exposed to his predecessor's experiences, and refinements are incorporated on the next trip.

Instrumentation is used on each first trip, down to the level of instructor driver. After two trips observing followed by two trips driving, a driver is examined and certified. Further refinement follows during normal duty, as drivers for example get opportunities to stop and start at each lineside signal.

5.3 Critical Train Handling Situations

The most difficult train handling situation is encountered when traversing a crest. The grade component of the portion of the train which is over the crest acts cumulatively with the tractive effort of the lead locomotives. This results in quasi-static forces sufficient to fail a knuckle near the middle of the train. The situation is critical when passing from the new 0,625 % ascending grades to the old 1,52 % descending grades, and hypercritical when passing from an old 1,52 % ascending onto a 1,52 % descending grade. The latter occurs at a few sites only, where use of momentum was planned as a cost saving alternative to flattening a grade. Two techniques are employed to overcome this problem. For short ascending grades kinetic energy is imparted to the train ahead of the rise, so that low tractive effort can be exerted after the crest. After long ascending grades, tractive effort is modulated such that the train accelerates at 2-4 km/h per minute until it is sufficiently far over the crest. Extremely low accelerations are almost imperceptible on a speedometer, but class 11E locomotives are provided with an accelerometer to facilitate this technique. It is forbidden to attempt to restart a heavy train over a crest.

5.4 Longitudinal Force Surges

Objectionable longitudinal force surges can be induced when modulating dynamic braking effort too rapidly. Tests have indicated that standard friction drawgears are too sticky. Because dynamic braking does not risk knuckle failure, jerks of a magnitude which in traction would cause failure, may be applied. There is thus no inherent safety valve, and the problem must therefore be contained by training drivers to modulate dynamic braking very gently. This is a sub optimum solution which will ultimately be superseded by providing drawgear with more suitable friction characteristics.

6 CONCLUSION

Successful operation of 200 car trains on the Ermelo -Richards Bay line has been achieved. Design parameters have been structured so that drivers perceive train handling to feel correct in their hands. Drivers are confident in their trains and in their ability to handle them. Dynamic augments on top of quasi-static coupler forces have been kept as low as 20 %, which is indicative of a very high standard of driver training. Design performance is being delivered in practice.

7 REFERENCES

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APPENDIX 1: LOCOMOTIVE CHARACTERISTICS

Class	Power	Mass,	Wheel	Traction	Dyn. Br.

	Source	tonnes	Arrgt.	Rating	Rating
6E1	DC	89	Bo-Bo	2,2 MW	Variable
7E	AC	126	Co-Co	3,0 MW	1,7 MW
10E	DC	125	Co-Co	3,0 MW	2,2 MW
11E	AC	168	Co-Co	3,9 MW	4,5 MW
34	Diesel	111	Co-Co	1,9 MW	1,4 MW
37	Diesel	125	Co-Co	2,1 MW	1,7 MW

Fig. 1 Graphical Optimisation

Fig. 2 Train Dynamics Instrumentation Vehicle

Fig. 3 Energy Consumption

Fig. 4 CRT In Driving Cab

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