Los Angeles Commuters Go Back to The Train

Transition from street-running to rail track approaching downtown Los Angeles.

One of the fastest growing areas of the railway industry is the light rail business, with so many new lines under construction, or being planned, that it has become almost impossible to keep up to date with the changes which are taking place. However, one particularly significant milestone was passed in July 1991 which deserves particular attention. When the Pacific Electric Red Car service ceased operations 26 years ago, Los Angeles became one of the largest cities in the world which did not have an urban rail transit system, but now the City of the Automobile can once again offer an alternative for commuters to congested freeways. The 22 mile Los Angeles Metro Blue Line is now operating between the city centre and Long Beach, using state-of-the-art Light Rail Vehicles (LRV's) on an entirely new track structure. This is just the first phase of a planned network of heavy rail, light rail and commuter rail which will extend over 150 miles of Los Angeles County by the early part of the 21st Century. The entire length of the Blue Line will be open by mid-1991, followed by the heavy rail Metro Red Line and the fully automatic light rail Metro Green Line by the end of the decade.
Blue Line Permanent Way

The Blue Line service is being provided by Japanese-built articulated LRVs, usually working as two-car trains, with a maximum axle load of about 10 tonnes. The track comprises 115RE (57.5kg/m) rail at 48 ft (14.4 mm) gauge, but with three different track forms.

Where the running is totally segregated from road traffic, the track at grade has pre-stressed monobloc concrete ties on stone ballast with "Pandrol" type 2D3535 rail clips. Glass Reinforced Nylon (GRN) insulators and "Pandrol" 10mm studded rubber rail pads. On elevated structures, and in the tunnel which brings the railway into downtown LA, a non-ballasted track form is used with a "Lone Star" direct fixation fastening system incorporating "Pandrol" type P6601 rail clips. However, much of the track runs along the centre of busy city streets. Although trains and road vehicles do not share the right of way as they do in a traditional tram or streetcar system, road traffic does cross the track when turning left into side streets, and emergency vehicles may also use the light rail track. In such areas the rails are fastened to concrete sleepers using an arrangement similar to that used for the ballasted track, but the sleepers are cast into a concrete track slab. The roadway is then formed by precast or cast-in-place panels which are placed over the track. The result resembles a continuous level crossing, and allows a standard rail section and the "Pandrol" resilient fastening system to be used for the first time in a steel-running Light Rail application.

Rail Pads

From the outset, Los Angeles County Transportation Commission engineers recognised the importance of providing a highly resilient rail fastening system, and they specified extremely low values of vertical stiffness for the rail pads to be used on the ballasted and steel-running tracks. However, the steel-running tracks in particular had to be designed for low maintenance, as removal of the road panels is only to be undertaken for infrequent major work. Consequently the rail pads had to be very durable, as well as resilient. Following their development work on resilient pads for high speed and main line applications, Pandrol were able to make small changes to their proven design of studded natural rubber rail pads in order to meet the LACTC requirements.

Special trackwork

In general, turnouts and crossings have been constructed on wooden ties with either "Pandrol" rail clips or cut spikes for rail fastening. Of particular interest are a number of crossings, where the Blue Line runs alongside the main Southern Pacific freight line towards the Ports of Los Angeles and Long Beach. Here many industrial sidings cross the Blue Line tracks, and novel crossing designs have been used to allow the freight trains and LRVs to operate together.

Panel 1 is to acknowledge assistance from Brazil's Guidon and Lawrence Wilde of LACTC who assisted in compiling this article.
Concrete Sleeper Rail Seat Erosion

The phenomenon of the migration of the sand and cement fraction of the concrete from the rail seat areas of prestressed concrete railway ties was first observed in North America some four years ago. In the meantime many examples of the phenomenon have been revealed over a wide geographic range in North America to an extent which could reasonably be called "epidemic proportions." The problem is severe in curved track, and generally increases in severity as the curve radius decreases, but it has also been observed in tangents. To date, apart from one isolated incidence in Australia, we have not heard of any other examples of erosion occurring outside North America.

A similar phenomenon occurs on concrete deck road bridges where the same type of erosion is experienced in the common track of many passing vehicles. There the cause is believed to be a water pumping action when the road is wet, where an approaching tyre forces water into the pores in the concrete surface and sucks it out again as it passes.

Pandrol International Limited requested assistance from the University of Texas to identify the source of the phenomenon and a remedy. The Cotain Concrete Company, in association with the Canadian Pacific Railroad had already commissioned Aetna University in Birmingham, England, to look at the influences of the concrete constituents and method of manufacture upon the development of erosion. In their workshop, England laboratory, Pandrol International Limited embarked upon a programme to try to reproduce erosion and to develop some means of evaluating and predicting the performance of candidate repair systems.

The cause is still not confirmed, but it appears most likely to be generated by an hydraulic action which can be accelerated by the presence of detrimental hard particles, like locomotive sand. The hydraulic action is likely to be excited by vibration in the rail seat area very possibly at the first and second symmetrical resonances of the tie when accelerations are very large. The rail and tie are vibrating out of phase and generating a pumping action, although the displacements will be very small.

It is very significant that the erosion follows the pattern of the rail pad and extends well beyond areas which would normally be expected to be carrying vertical loads. Erosion occurs with all types of rail pads, from relatively flexible rubber to relatively stiff plastic, like EVA and HDPE, and with all types of fastenings. It appears to be independent of the rail clamping force and stiffness and only marginally dependent upon the stiffness of the rail pad. However, at sleeper resonance frequencies, all the pads seen, where erosion took place, will have been effectively rigid. The eroding medium would be moisture trapped between the rail pad and the concrete surface. It has been surprising how frequently moisture has been observed at this instance. Sometimes, long after there has been any rainfall, the reason that the phenomenon appears to be restricted to North America probably lies in three possibilities:

- axle loads in North America are much higher than almost everywhere outside, viz: 37 T x 27 T max.
- North American tie uses, almost invariably, little or no entrained cement to stabilize freeze-thaw cycles and therefore have more interstitials into which water can be pumped.
- North American railways generally transport vastly larger tonnages than European railways, perhaps the primary factor has only been delayed.

The repair of bridge decks and other concrete surfaces, like airport runways, has traditionally involved the use of a patching film, even low or epoxy or polyester based on an impropionic material like methyl methacrylate. The University of Texas undertook a survey of published literature and data and their laboratory tests on the most appropriate candidate materials and systems. The tests covered adhesion properties, moisture, and adhesive properties during temperature cycling, cure time and workability. The test results were sufficiently attractive to encourage the view at Pandrol International Limited that a practical repair system was a likely possibility. Meanwhile, in the workshop laboratory two approaches to testing were pursued:

1. a conventional inclined load test which was later changed to an "Eisenmann type" swinging arm test with a constant application of water to the rail seat area
2. a high pressure water spray system applied to the tie.

The first system produces erosion but requires very extensive loading and takes a great deal of time. The second system was developed into a rig which produces a 1 kg. water sample in ten minutes, and has been generally adopted as a basic to test and to study the relative influences that the matrix constituents and proportions have upon abrasion resistance of the water flow. A wide variety of repair materials have been subjected to the water test with results varying from no improvement in the test material to erosion requiring very little abrasion after two hours. On raw concrete, North American sourced air entrained ties erode, repeatedly, at about twice the rate of U.K. produced, non-air entrained ties. So far there has been no obvious other factor but we are neither comparing totally similar products, nor are we sure that the water spray test is relevant to the type of failure experienced in track. The factors which have been researched are:

- type of resin
- type of curing agent and proportion
- type of accelerator and proportion
- type of filler and proportion
- temperature of substrate
- temperature of resin mixture
- method of application
- method of cure
- and their effect upon:
  - abrasion resistance
  - cure time
  - workability
  - pot life

From this data, an epoxy resin based formulation has been selected which gives optimum results. For maximum adhesion the sleeper surface is best sound blasted and thoroughly dries before the application of the resin and the resin surface must be protected against moisture until it is cured.

For practical application, this process has been restricted to manual application of the resin mixture. Canadian National Railway has developed a simple mask to guide the manual application and an hydraulically powered, vertically spindled, milling type machine to dress off the surface of the dosed material. Pandrol International Limited is developing a mould and pressure injection system which is giving very satisfactory results in a manual configuration. The opportunity to automate the material mixing and injection is being investigated.
Neither Texas University nor Pandrol International has been successful in developing an impregnation system. No sealant has withstood the water spray. As an alternative approach, the possibility of sealing the rail seat with the rail pad has been investigated. Using soft compounds it would appear that an effective seal can be developed with a rubber pad but its durability is very poor. Increasing the durability of the pad invariably involves increasing its stiffness, decreasing its dynamic performance and reverting to the conditions under which erosion occurred in the first place.

Experimental work to identify a treatment for new concrete ties, either during manufacture or immediately afterwards has not, so far, yielded a practical solution. Clearly new sleepers could be cast with a rebate into which an epoxy resin could be injected but this would be an awkward and expensive process and would not bear comparison with a method which could be incorporated in the conventional manufacturing process.

Acknowledgements
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- The University of Texas at Austin
- The Texaco Chemical Company
- The Constain Concrete Company
- CXY Incorporated
- Woma (UK) Ltd
- Shell (UK) Ltd

Together with the suppliers of proprietary materials made available for comparative testing.
The second stage in the recent expansion of the Pandrol Group was the successful negotiations in January 1990 to acquire Jackson Jordan and 100% of Speno Rail Services, which were merged together to form Pandrol Jackson Incorporated.

Effective maintenance of rail resources by a railway system requires detailed information concerning existing rail conditions. Armed with this data, priorities can be determined and budgets formulated for grinding work to be done as well as for longer range needs.

Since 1984, the introduction of the RA-204 Rail Analyzer, Pandrol Jackson engineers have been concerned with providing accurate measurements of rail surface conditions. The RA-204 system has established itself as the leader in this technology in the North American market while two other suppliers of this measurement service have abandoned their efforts. The patented RA-204 system is increasingly requested by major railroads to provide a qualitative means to assess the need for rail repair by grinding, rail replacement, or rail transposition.

In 1990, this system was used on the Santa Fe, Canadian Pacific, CSX, and Burlington Northern Railroads. Virtually all of the current Canadian Pacific rail grinding programmes have been planned with the aid of Pandrol Jackson software and the data from the RA-204 measurements. On the CP, the RA-204 Analyzer measurements are made two to four weeks immediately preceding the grinding operation. The data is analyzed in several stages to produce a grinding forecast that is easily used by the railroad personnel to direct the grinder operation.

In 1986, Jackson Jordan produced its first Switch and Crossing Grinder, the SCG-23, considered the premier machine in the North American Industry. With the merger of Jackson Jordan Inc. and Speno Rail Services into Pandrol Jackson, an enhanced capability now exists to combine the technologies from both companies to provide a “Total Solution” for rail reconditioning. This concept will integrate the three processes: rail measurement, rail grinding planning and rail grinding.

Rail Measurement

Rail surface conditions are measured by the RA-204 Rail Analyzer Vehicle. The RA-204 is a self-propelled Hi-Rail vehicle designed for evaluation of railhead surface conditions. Its patented systems measure and retain a permanent record of both the longitudinal and transverse profile of both running rails.

The RA-204 can record and identify the following rail geometric parameters:
1. Corrugations in wavelengths from 2 to 50 inches (50mm-1,270mm)
2. Discrete defects
   a. Low and high welds
   b. Engine burns
   c. Battered joints
3. Rail running surface radius
4. Rail running surface angle
5. Railhead width
6. Rail height

Testing speeds vary from 1 mph to 25 mph (1.6km-40 kph) depending upon rail conditions. Typically, 100 to 125 miles are tested daily. The data collected is stored on computer magnetic tape for later analysis at the main office. Two auxiliary power units provide electrical power for the computer and associated electronics as well as lighting, heating and air conditioning systems.

The RA-204 uses a contact measurement system specifically designed for precision measurement at speeds up to 25 mph (40 kph).

Measurements are made from a 56 inch (142mm) long reference beam which was designed to maintain a fixed orientation to the centreline of the rail. Three measuring wheels are located at the centre of the reference beam, at the same transverse cross-section of the rail and thus can be used to measure both corrugation and transverse rail profile. A specially designed pneumatic system is on the measuring wheels to maintain contact with the rail surface throughout the full test speed range. The three wheels are positioned by a special gaging system, one at the rail centrel ine and the other two at 1 inch (25.4mm) each side of the centre. The position of each wheel is electronically sensed by a position eddy current transducer which generates an output proportional to the wheel displacement in the range of 0 to 0.256 inches (0.65mm). While corrugations are measured generally between 0.005 (0.125mm) and 0.060 inches (1.5mm), the remaining range gives very useful measurements of other rail surface defects.
Two optical laser sensors provide signals used for determining rail side wear while two ultrasonic transducers provide rail height information. An event panel is located near the operator for display of track location and for entering topographic information to the magnetic tape record, such as:
1. Location: Milepost and footage
2. Curve: Type (right, left, start, and end).
3. Events: Switch, Crossing, Signal, etc.

The quality of all signals being stored on the magnetic tape is constantly monitored by the operator on a video display in real time.

Grinding Planning and Forecasting

The Need

Early in 1987, Pandrol Jackson engineers were contacted by a major customer and requested to produce computer software that would automatically create a rail grinding programme from RA-204 data. Since the data was currently being used in a manual fashion for grinding planning, the project seemed straightforward, and was undertaken. The result, after much work, was a software planning tool that is still evolving today. Since actual rail conditions are extremely varied, the grinding solution is very complex and relates to a large number of parameters. A detailed process of optimizing the software over several years has resulted in a solution to the problem that has now been proven in the field to be a proper approach.

The benefits of using this approach are:
- removal of subjectivity from grinding decision making
- ability to forecast grinding over large areas for budget purposes, and to prioritize grinding on a realistic basis
- reduce grinding decision making to a level that more people can understand. Prior decisions tended to be made by a single grinding expert on each railroad and were very subjective.
- aids our customers who, because of the general trend towards reduction of their engineering staff, require outside help in making engineering decisions.

The Process

The RA-204 measurements have been reduced to a variety of reports to suit the needs of our individual customers. The data is summarized over a defined length of track, referred to as the “segment length” while this length can be variable: the most common selection of our customers is 100 feet for curves, and 528 feet for tangent track. Information supplied on a standard form includes the following for each segment:
1. Segment Location: Milepost and feet
2. Track alignment: Tangent, Right or Left Curve
3. Corrugation Index: Roughness Index
4. Number of Corrugations Found in Segment
5. Running Surface radius
6. Running surface angle
7. Topographic Information: Signal, Switch, etc.

Using the RA-204 Reports, along with predefined limits for the various aspects of interest to the railroad, sections of track are identified as requiring some amount of reconditioning. The type of reconditioning needed, in terms of patterns and passes, can be determined from information contained in the

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Future Development

Pandrol Jackson is committed to the idea that the "Total Solution" concept can be a continually evolving process. As technology improves or customer requirements change, the corresponding processes are being improved and updated. Currently in development are:
1. Non-contact measurement system
2. Adding profile measurement devices to grinders for quality control
3. Automatic pattern selection based upon real-time rail measurements
4. Improvements in rail grinding systems for more consistent quality. Working closely with each railroad to produce a solution tailored to their requirements has allowed Pandrol Jackson to produce measurement software and grinding planning software that is ideally suited to the needs of the North American grinding market. This technology will play a significant role in ensuring Pandrol Jackson's success in the rail grinding market of the 1990's.
**RTS-BSCAN System**

This system provides a rail flaw detector car, which is located in real-time, with a picture of the side and end elevations of the rails under test with detected flaw signals displayed in the identifying colours. Advanced parallel processing techniques are used to process and analyse the data captured by the wheel mounted ultrasonic transducers and provide the operator with a user-friendly control system, directed from a touch screen or a standard keyboard. The sophisticated pattern recognition programme is designed to minimise false alarms. All data is stored and can be called up on a later date, or hard copied for verification or examination processes.

In the area of ultrasonic nondestructive testing, Dapco Industries has been an industry leader in the use of systems which are organised in a multi-processor architecture. In conjunction with research work done at the University of Connecticut, Dapco has recently developed a new prototype system, and has carried out real time techniques for automated rail inspection systems and rail flaw classification. This work has led to the development of practical systems which are currently in industrial use in both the pipeline and rail industries (Dapco RTS 100 Flaw Detection System). Dapco is currently developing a number of other systems, including the RTS-BSCAN, which will incorporate further advancements in areas of pattern recognition and visualisation for real-time systems. However, as an interim system a modified RTS-100 system called the RTS-BSCAN has been developed. The RTS-BSCAN function for rail applications was first evaluated at the VDOT show in Zurich, Switzerland, where the software has undergone substantial revisions to enhance the operator interface.

The RTS-BSCAN is a system which allows the operator to view flaw information with a much greater level of detail. The system provides an enhanced graphical presentation of the rail in either profile or cross section. All detected flaws are mapped out on a grid and coordinates with different colours representing responses from different channels. A particular flaw pattern is used to transform the transducer responses into the 2-dimensional grid representing the rail.

In addition, the RTS-BSCAN system has the ability to recognize basic flaw patterns. Each flaw pattern is specified as a combination of channels and channels which are spatially correlated. When a basic pattern is recognised, a three letter code (such as TDF or YSH) is displayed. The RTS-BSCAN system will use the basic recognition to make higher level decisions about the presence of a rail joint area.

The RTS-BSCAN system maintains Dapco’s tradition of a user-friendly interactive environment, to provide ease of operation as well as a combination of efficiency, thoroughness and speed of operation in flaw detection not achievable by other methods. The RTS-BSCAN offers significantly increased pattern recognition capability, a greater automation potential and reduced false alarm rates. Also, the RTS-BSCAN provides an increased user-visualisation capability during operation, through a careful analysis of collected fault data sets and graphic presentation. The RTS-BSCAN will maintain testing speeds faster than those of present RTS-100 systems (ISP inspection speeds of 15-25 miles per hour, depending upon test density and vehicular selection).

In order to provide a high level of capability while maintaining a high data testing rate, a distributed, multi-processor configuration for use is achieved. Each processor is used to transform the transducer responses into the 2-dimensional grid representing the rail.

In addition, a special graphics depicted computer (IPC), with high performance graphics interface and monitor, is used to provide the operator with a user-friendly interface to the system. Additionally, the IPC is used to display the operator with a user-friendly interface to the system.

The Ultrasound-Based, Computerized, Flaw Detection/Recognition System contains several new high-speed communications boards which have been designed to apply computer processing methods in real-time to ultrasonic-based information about the rail integrity. The system is self-contained, user-friendly, and offers a high speed, consistent decision making environment for rail testing applications. Stored, pre-calibrated data sets allow immediate set-up of the system for alternative rail sizes. Hard copy exception reports may be generated during the testing process upon request. The system provides the operator with a near real-time presentation of the rail flaw content and identity for both rail systems simultaneously during operation on a colour graphics display as shown in Figure 1. This display corresponds to the group of flaws as shown in Figure 2. A second display contains a touch-sensitive screen through which the operator can control the operation of the test system.

Visually all of the control functions are available through a menu selection by pressing predefined areas of the touch screen, or alternatively through the use of an alphanumeric keyboard.

Normal operation, once the system has been calibrated, is automatic. An operator is required to start the system and load a set of test parameters before the system will begin collecting data. The operator may also specify data such as the location of the rail which is to be tested for inclusion on the hard copy report. As the test moves along the rail, the ultrasonic data which is being collected is processed by the distributed computer system to recognize the specific ultrasonic data profiles peculiar to each flaw type of interest. This process includes the detection of potential flaw “events”, the creation of a volume profile of the flaw locations, comparative evaluation of the resulting multi-channel and 2-dimensional data with built-in flaw models to complete the detection/ recognition process. As probable defect areas are recognised by the system, the rail automatically marked by paint guns to help locates areas for repair. The operator may review the graphical presentation of the recognised defect data set to confirm the analysis, or the marked rail areas may be hand-scan verified for visualisation. After confirmation, the system will continue with its data logging and reporting functions. The RTS-BSCAN continues Dapco’s policy of providing all system control functions through “Test Parameter Update” screens on the computer. All test parameters can be stored and recalled at any time for quick and efficient set-ups for varying rail sizes. Thus ensuring the most effective testing for each rail size.

The graphical and visualisation subsystem can provide a detailed view of flaws as they are recognised. This data can be reviewed by an operator to help verify the detection, and thus the location can be dual-checked on a printer. The presentation format, for real time operation, is shown in Figure 1. The operator is also provided with further presentation options.

In order to aid the control and reduction of false alarms, the RTS-BSCAN applies several stages of hardware and software processing. To help reduce the false alarm rate, both a fixed threshold baseline and an adaptive, software-based time/variable threshold parameter can be utilised. The adaptive threshold can help avoid interference from system noise, and spurious responses which might come from understandable underhead reflections, etc.

Correlation of multiple channel operation is based on studies of expected response patterns for different flaw categories, and is used to aid the selection/rejection of other “unexpected” responses which do not relate to the desired detection process for a particular flaw category. This process is carried out as a feature extraction process.

A second area of real-time detection and pattern recognition for nondestructive test applications, it has become necessary to stage ever-increasing data rates while also achieving higher resolution and more sophisticated pattern recognition. These two needs create contention in system resources, since higher data rates demand shorter processing times to achieve the needed functions, while higher sophistication and resolution demands longer processing times. Current single processor systems are unable to meet these needs effectively. The RTS-BSCAN system described here has been developed to resolve this problem. A hierarchical approach is used to distribute the total pattern recognition task into a set of stages with which the recognition at one stage provides input results for the next stage. The stages are defined in a manner to accommodate essentially all aspects of the pattern recognition programme, and also to relate directly to a pipeline, distributed processing architecture. This allows the total pattern recognition task to take advantage of distributed processing hardware to achieve real-time operation effectively in a simplified format which is not possible with other approaches.

**Fig. 2. Two rails showing location of flaws**

c) Feature extraction (boolean, relational algebra)

b) Basic anomaly recognition (clustering, geometry, graphics)

c) High level pattern recognition (automata theory, context analysis, artificial intelligence)

e) Each of these levels implements a function which is commonly found in one or more pattern recognition approaches. However, the RTS-BSCAN system is able to integrate the sets of activities in a composite recognition system suitable for real-time, distributed applications. In that manner, only the first stage must really keep up with a potentially enormous incoming data rate; the subsequent stages experience decreasing input data rates as the relevant information is extracted from the arriving data samples. Each stage is intended to be mapped out onto a distributed, pipelined system such that each stage has the same utilisation.

In the future, the RTS-1000 will extend the event detection spatial transformation, feature extraction, anomaly recognition and pattern recognition to three dimensions.
Track Design for Very High Traction Forces

As the performance of a train of any kind is increased with the introduction of new technology, it may become necessary to take a fresh look at the way in which track components are designed to cope with changes in loading conditions. One area in which this has become particularly obvious is in designing track to withstand forces imposed by Heavy Haul locomotives operating with very large traction efforts.

The total amount of traction that any locomotive can produce is a function of its power divided by the weight it is supporting. However, stating that limit is by the ability of the smooth, steel wheels to grip on a smooth steel rail. This limit can be increased by increasing the weight per axle, and by using control techniques which allow every wheel to be driven almost to the point of slipping without any wheel "setting go." The effects of this on the track structure are not immediately obvious, but research carried out in the last three years has shown a close correlation between some "mysterious" track deterioration phenomena on heavy Haul lines, and the use of very high traction forces.

Longitudinal forces in the rail (i.e., forces acting along the line) may be generated by traction and braking forces, or by temperature changes in continuously welded rail. For most applications it is last factor which is of overwhelming importance. Consequently, the standard design and test techniques used by the railways and rail fastening suppliers are intended to ensure that the rail will not move through the fastening and thus allow thermal expansion or contraction which could result in track buckling in hot weather, or rail breaks in cold weather. Such failures occur only if a significant amount of movement takes place. Thus, for example, the test specified by ARE.A for concrete sleepers requires that the fastening system hold the rail with 0.2 inches (5 mm) of its starting position for three minutes on the application of a longitudinal force of 2400 lb (1072 kN) with no external vertical load applied. In the case of high traction force the forces on any one rail seat are never likely to be as high as this, and are only applied for a fraction of a second. But if they are applied very frequently very much smaller individual displacements may accumulate and become significant. There is also likely to be an influence from the vertical load applied, and the frictional restraints in the rail fastening system may be significantly reduced by vibration excited by dynamic forces.

On-track and laboratory tests have now been carried out to determine the actual longitudinal displacements which occur under heavy Haul traffic. Some preliminary results of these tests were included in the 1988 edition of Track Report (Fig. 1). These indicate that as each wheel passes over the sleeper the rail moves by a fraction of a millimetre, but that it then "springs back" once the wheel has passed. If the longitudinal force is very high, that recovery may not be complete and the rail could be left perhaps a few hundredths of a millimetre from its original position. Under such subsequent traffic the whole track structure will tend to shake back to an equilibrium position, and in most cases these occasional small displacements go unnoticed. However, if a large proportion of trains are operating at high traction effort, and if that effort is sustained over the same section of track by all of these displacements the trajectories can begin to accumulate.

The ways in which this process manifests itself, and thus the most appropriate preventative or corrective actions, depend on many other parameters which may be peculiar to a particular railway or location. Any deterioration will always begin at the sleepers which carry the highest loads, so that the critical parameter is not the average longitudinal force applied to the sleepers over a length of track, but the highest local value of that force. This can be minimised by ensuring that the track support is as uniform as possible. Typically, if there are variations in the quality of ballast maintenance it is at the most tightly packed sleepers that problems are likely to appear first of all. However, this is not the only part played by the ballast. The ability of any (s) surface to slide over another depends on two factors: the frictional resistance of the surfaces, and the amount of load applied to press them together. In the case of ballast track there are two interfaces which could conceivably slip—that between the rail and the sleeper, and that between the sleeper and the ballast. Of the two, the rail-sleeper interface is generally the smoother, but even when there is no train present to provide a vertical load there is a large clamping force due to the rail clips. Conversely, the sleeper-ballast interface is much rougher, but in the unloaded condition it has only the weight of the rail and sleepers to provide a vertical force. Thus, under little or no external loading, the rail-sleeper interface offers the greater resistance to longitudinal slip (Fig. 2a). However, if a large vertical load is applied the rough surfaces of the ballast and sleeper tend to "lock" into each other and that offers more resistance to slip than the rail fastening (Fig. 2b).

In practice, very high traction forces will always be accompanied by high vertical loads, because they are needed to provide the adhesion to exert the tractive effort. When a loaded wheel is adjacent on a sleeper the interface between the rail and sleeper will be the most susceptible to slip whereas when the track is unloaded or more lightly loaded by empty trains, the more susceptible interface will be between the sleeper and the ballast. The latter condition may also apply under non-driven loaded axles when there is a significant source of dynamic excitation. The result of this mechanism is that very high traction effort is the slippage of rail through the fastenings under the passage of locomotives, which is accompanied by the elastic extension of the tractive forces and generate similarly disturbing forces.

This leads on to the all important questions of Prevention and Cure. Firstly, it is necessary to identify areas where the problem may occur. From observations to date, it would appear that on well maintained track the tractive efforts of at least 390 KN (80000 lb) per locomotive are required to generate slip of the kind described, and that significant accumulated slip is only likely when such forces are applied for sustained periods over the same section of track several times each day. Thus the only likely location for this kind of failure is on a long gradient against loaded trains on a dedicated Heavy Haul line, although the general trend towards more powerful locomotives for freight operations worldwide may begin to offer other types of railways into this category.

Secondly, there is the matter of ballast and formation. The maintenance of a uniformly well packed ballast section on a good formation may be sufficient to raise the threshold condition for this type of track failure to a level which will not be reached but the most extreme loading conditions. Finally, the rail fastening design may be significant. Figure 3 shows schematically some longitudinal force-displacement curves for two different rail fastening designs, both of which just meet the ARE.A Chapter 10 requirements, and which are thus both expected to have equally good resistance to thermally induced rail creep. However, curve number 2 remains linear to a much higher load, Pmax, and deformation than curve 1. It is first departure from a straight line which determines the resistance to the tiny amounts of slip which occur under individual wheel passes rather than the conventional longitudinal creep resistance technically. Uc in fig 2 is determined from P or Pmax in fig 3 rather than Pmax and thus the fastening system giving curve 2 is expected to be better suited to these severe heavy Haul conditions than that which gives curve 1. The differences between the two may in fact be quite subtle. For example, changing the rail pad in an existing assembly has been shown to have a much greater effect on the resistance to slip under traction than it has to its resistance to conventional rail creep. This observation has led to efforts to develop pads which have suitable properties but which also meet all of the standard requirements, and are durable enough to survive in heavy Haul track.
Grinding Rapid Transit Systems

Pandrol Jackson computerised production switch rail grinder keeps BART commuters riding in comfort

The Bay Area Rapid Transit System (BART) in San Francisco, California has recently received Pandrol Jackson’s first rail grinding machine sold to a rapid transit system. The Model SCC-23 Rail Grinding Machine delivered to BART is the 12th machine of this type built by Pandrol Jackson. The previous eleven machines are in PJ’s fleet of rail grinding machines that are contracted to various North American railroads as a switch and crossings grinding service.

Since delivering the BART machine, PJ has also received an order for an 8 stone rail grinding machine from the Vancouver BC Rapid Transit System. Engineering work on this machine is ongoing and shipment of the machine is scheduled for Spring of 1991. Rapid transit systems are an expanding market for rail grinding machines that PJ expects to pursue aggressively in the 1990’s.

The following article was furnished by Vince Mahon, Department Manager of Power and Way Maintenance for the BART System.

The San Francisco Bay Area Rapid Transit System (BART) is a 73 mile double rail system designed for 66 inch wide gauge, laid with 1 1/4 rail. The system is a high speed electrified fully automated transit system. Trains consisting from 2-10 self-propelled vehicles are capable of operating at 80 mph. Through the use of maintenance crossovers and control of trains in a reverse running mode, maintenance work on the road bed can be accomplished between 2000 and 0400 hours without any serious disruption to normal service.

BART first opened for revenue service in 1972. At this time BART had purchased a 24 stone rail grinding train to remove mill scale from the running surface of the newly laid rail for the purpose of train detection and reduction of wheel slippage during the braking and accelerating mode of trains. A maintenance grinding program was initiated to remove corrosions as they developed and keep the noise level down. As additional trains were added to the system and train lengths were increased to accommodate ridership, it was noted in 1987 that the grinding maintenance program and the equipment that had been purchased in 1972 were unable to keep up with the removal of the corrugations that were developing in length from 2-6 inches through the system. Corrugations in the head of the rail were causing a noticeable difference in the riding quality of the track. The noise level generated by the vehicle wheel/rail interface was reaching an unacceptable level.

With rail tonnage reaching 132,420,414 gross tons and rapidly increasing, a decision was made that a new rail grinder would be purchased, being of the state-of-the-art of the industry, to increase rail grinding productivity. The specifications called out for a production switch rail grinder with a completely computerised system for controlling all grinding operations, including re-profiling of running rail and switches. The production of this machine was to remove, 008 inch in depth, in one pass at a minimum speed of 3 mph in the area of the wheel wear pattern on the running surface of the rail. The specifications also required grinding through turnouts and switches at a speed of 3 mph. An additional important item in the specification was a requirement for grinding profile patterns which could be custom-designed for the BART system, allowing the operator to change or select rail grinding or rail profiling patterns as necessary from the operator’s station using the computer data base information.

A contract was put out for bid in 1989 for the described grinding equipment and Pandrol Jackson was awarded the bid. A 20 stone grinding unit was delivered in September of 1990. All tests were performed per specifications and the grinder was put into service during the month of October 1990 without any major problems. We find that the quality and production rate being accomplished has met our expectations. It is apparent at this time that the capabilities of the Pandrol Jackson computerised switch rail grinder will meet our requirements for:

- Removal of rail corrugations at speeds up to 3 mph
- Rail profiling – Allowing re-profiling of the rail for compatibility between the wheel/rail interface relationship
- Noise reduction – rail profiling and rail grinding capabilities contribute to reducing wheel/rail generated noise by approximately 10-12 decibels
- Maintenance grinding can be accomplished at speeds up to 5 mph
- Switch grinding maintenance – will add service life to switch points and frogs

All of these features in the new rail grinder add up to a very important commodity in our business. Providing the Patron with a Smooth Comfortable Ride. The new Pandrol Jackson computerised grinder that was recently received on our property will be a major factor in maintaining our rail conditions to meet our smooth ride goals.