HISTORY AND DEVELOPMENT OF NON-INTRUSIVE ELECTRICAL TESTING AND ASSESSMENT OF DC TRACTION MOTOR ARMATURE CONDITION AND RELIABILITY DURING OVERHAUL

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1.0 BACKGROUND

1.1 Brief Historic Background:

Queensland Rail's (QR) historical background extends back to the era, where it was part of the original developing Australian transport system. This was the era before roads were viable and passable in all weather conditions. QR was therefore originally a people and farm produce mover to the ports and major cities on the east coast, and a means of shifting machinery, processed food and building products into the landscape as settlement extended into the interior. In fact QR was originally three separate rail systems - namely, the Southern Rail (a hub system extending from Brisbane to the upland plateau of the Darling Downs), the Central Rail (extending out from Rockhampton to the Central Tablelands and interior of Queensland) and the Northern Rail system (servicing the Townsville and Cairns areas and tablelands behind - later to extend and service the Mt. Isa Mine). It was only as a strategic measure that the three rail systems were linked to provide a rail link north to Cairns. This has left QR with a highly decentralised rail system with some 9,357 km of rail network (- whose structure traditionally followed the three original separate rail system's networks and locality), spread over a land area that is roughly equivalent to that of seven times the land area of the United Kingdom. The difficulty for QR, and transport in general in Australia, has always been the distance separating the commodities requiring transport, and the highly urbanised coastal fringe where port and manufacturing facilities exist. (Australia has an estimated 85% urbanised population).

1.2 Qld Rail's Commercial Background:

QR, as in common with many other rail networks, has been a (State) Government funded and run service. Major changes in the traditional structure of QR occurred when bulk commodity (i.e. coal, sugar, wheat and the like) became a major product to handle during the late 1960's. Since this time, the traditional Divisional business approach (which handled all freight in the area) has undergone major change - to that of being oriented to specific traffic task type.

QR now has the following separate identifiable business groups -

- Coal and Minerals Group;
- Freight Group;
- Passengers Group;
- Workshops Group;
- Chief Executive Officer's, Corporate Services & and Financial Services Groups, (these latter Groups are actually separate and are strategic management or service providing groups).

This process commenced over a decade ago, with the usual major re-structure of the management practices. This process will be completed in its major form, as QR is commercially incorporated in July 1995.

The commercial direction has now been changed from a divisional strategy (where cross-subsidisation of traffic can occur), to that of one where operational efficiency in a product line is now the driving force. This is common with most other rail system restructures that have occurred world-wide in the past two decades.

2.0 MOTIVE ROLLINGSTOCK CHANGING TECHNOLOGY AND ITS IMPACT ON OPERATIONAL EFFICIENCY:

QR operated up until the 1950's with a large fleet of steam locomotives. With the advent of cheap and reliable resources of petroleum products - the dieselisation of QR began in the late 1950's. Later, to take advantage of the huge coal reserves of Queensland (as petroleum was perceived as a limited resource), electrification of the major export coal lines began in the 1980's, continuing to this day in QR.

Since the 1960's, QR's motive rollingstock reliability and hence locomotive utilisation has been directly impacted on, by the reliability and availability of the electrical traction motors used in the diesel electric and electric (25 kV overhead) rollingstock.

With the arrival of the QR commercial policy (product service based efficiency) in the past decade the impact of electrical traction machine reliability has now come to the fore, being one of the major limiting factors on QR's system being able to deliver the freight task on time.

3.0 DEFINING PROBLEMS WITHIN QR'S MOTIVE ROLLINGSTOCK ELECTRICAL TRACTION MACHINES :

3.1 System and Geographic Limitations:

QR uses its motive rollingstock traction motors in a highly variable climate - from the Southern Queensland Highland operation of just below 0° Celsius operation for part of the year, to normal moist coastal operation during the summer months, to dry temperate operation in the winter months to that of tropical monsoon. Ambient trackside air temperatures in the tropics and coast can be as high as 50°C. This variation in climate (both seasonal and extreme) stresses insulation systems.

3.2 Narrow Gauge and Small Loading Gauge:

The second related problem, is due to QR being about as far away as is possible from all of the major electrical machine designers and major OEM suppliers around the world. QR also operates a narrow gauge (1067 mm) rail system with comparatively severe restrictions on its loading gauge. This has caused OEM designers major problems in the design of electrical power and traction control systems, cooling, commutator and motor/drive to wheel/rail structure (particularly for drive systems with machines above 300 kW) for motive rollingstock. Simply fitting the traction drive system into the locomotive equipment platform and bogie structure has led to major design compromises for the locomotive. Limitations and short comings in design, particularly with higher kilowatt traction machines and drives, have been, and will continue to be one of the major problems for narrow gauge networks like QR.

3.3 Increasing Workload and Duty for Electrical Traction Machines:

Combining such climatic variances and obvious or latent design problems with the overall operation efficiency gains of the past decade (i.e. the traction machines are working harder) has placed increasing importance on identifying major problems in traction machines, remedying design problems, and identifying machines that are potential failures during the normal operational life of the machines. The changing QR freight task can be appreciated by the overall increase in net tonnes from 73 million to 92 million over the period from 1985 to 1993. During this period, the locomotive population required to shift this freight task has decreased from 559 to 492 units (i.e. fewer higher kilowatt machines for the increased traffic task). This is reflected in the net tonne per kilometre gains, as shown in Figure 1 for the period of 1988 to 1993 (Nb: statistics are taken from QR's annual reports for this period).

4.0 REVIEW OF TRACTION MOTOR FAILURES:

4.1 Review of Related Causes:

With this trend in mind, it was noted during a survey in the year 1992/93, that only 45% of electric vehicle traction motors and 51% of diesel electric vehicle traction motors remained in service until removed for age related problems or

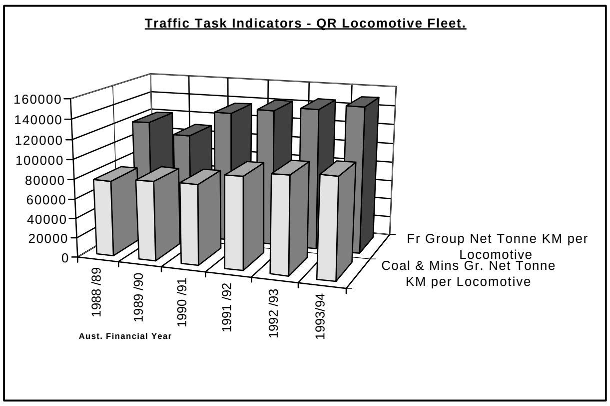
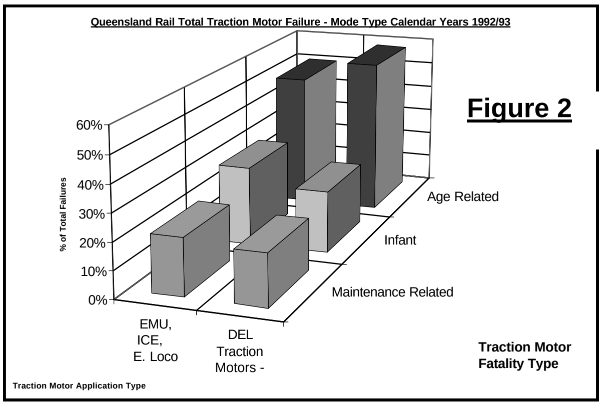


Figure 1

at the full overhaul operation lifetime (Nb: for reference - QR traction motors generally operate to a maximum life of three [3] years for passenger multiple unit vehicles, five [5] years for electric locomotives and up to seven [7] years for diesel electrical rollingstock, before they are removed on age grounds for overhaul).

All of the traction machine failures, for the period of 1992/93 financial year, were reviewed as to the cause related possibilities i.e. infantile related failure, maintenance related failure and age removal. The results are shown in Figure 2 for this financial year of 1992/93. Infantile failures are failures that are considered to be related to the repair of the machine, and fit into this category if the failure is within two (2) years of repair or overhaul and reflect the nature of the repair; maintenance failures are those related to short brushes and contamination by external sources or via the cooling air on electrical creepage areas within the machines. This type of categorisation allowed strategic planning to gain impetus. Infantile failures and maintenance failures are



within the scope of both the workshop and depot procedures, and provided the necessary information to implement a procedures review and a training response. This is now underway and implementation (including training material and new recommended practices) should be completed during the 1995/96 financial year.

4.2 Review of Component Related Failures:

Prior to this failure related cause review, in the years after 1986, QR began to identify the major component causes of failure. The statistics for these revealed that armature related problems were the largest single cause of operational failures. See Figure 3 for the history of prime cause of failure or removal from traffic for Diesel Electric Rollingstock (Nb: Electric Vehicles have a similar graph). In QR's case the armature showed the most potential for improvement. This is further justified by considering the consequential damage a failed motor can cause to the rest of the motor (particularly if the windings fail. Testing and proving the armature insulation, became the prime area of focus for the traction motor repair and overhaul. Figure 4 shows the history of armature type failures for Diesel Electric Rollingstock (Nb: Electric Vehicles have a similar outcome), and mirrors QR's efforts in identifying the two usual causes of DC armature failure:

- electrical failures;
- commutator related failures.

History points to a process of identification of commutator brush wear and related flashover damage. Since 1988/89, QR has been measuring and removing from traffic increasing numbers of out of round commutators with the view that motors with such problems are easier and less expensive to repair if flashovers and other consequent motor damage does not occur. This is mirrored in the increasing number of armatures removed for poor commutator profile, with a resultant decrease in the number of flashover damaged machines. Similarly, the identification of armatures having special electrical problems led to a new testing regime during the overhaul of the armature. Identification of Low Insulation Resistance (LIR) readings measured to frame earth started during 1991/92 as a means of identifying potential serious winding failures during the next operational period following machine overhaul.

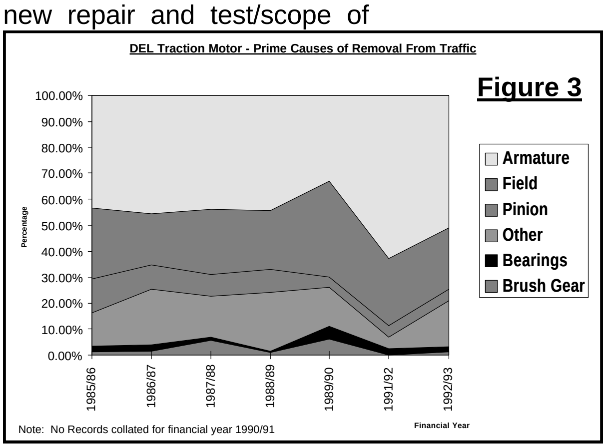
5.0 CHANGING ARMATURE TEST AND REPAIR SCOPE OF WORK AND PROCEDURE:

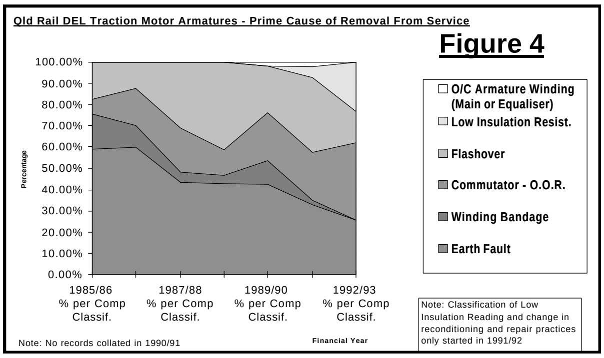
QR workshops carry out only the dis-assembly, stator component exchange and re-assembly of traction motors. Outside contractors are used to repair, recondition or rewind the traction motor armatures, stator component coils and the like. By using this approach, QR has retained its in-house knowledge of traction motor repair, while using the competitive advantage of having five major electrical contractors in the Brisbane area. QR however produces its own detailed rewind and repair specification for the armatures, while using OEM standards for the stator coil repairs.

With a standard rewind specification (based on either the OEM manufacturing specification or a QR developed standard alternative insulation systems(QR has the advantage of knowing exactly the insulation structure and placement of the armature winding. Examination of the structure has allowed the identification of the prime armature winding failure sites. These are -

- riser winding connections;
- winding knuckle end open circuits;
- winding stack inter-turn shorts;
- winding exit points from the core - related also to winding retaining bandage procedure and wedge tightness.

The standard recondition/repair of ten years ago, (a clean, bake, single point hi-potential test, Vacuum Pressure Impregnation (VPI) if required, commutator turn/undercut and balance), has now developed into a series of test and checks for a new repair and test/scope of





work as follows -

- Clean and dry, assessment of banding and wedge tightness and general insulation condition; general mechanical condition and tolerance check;
- Sensitive Ductor Test (sensitive enough to check partially equalised Lap wound armature circuits) to check winding riser connection and winding continuity; assessment of core loss and commutator stability;
- Initial Test : Pre-meggar, AC Leakage Trend Test, DC Leakage Trend Test, Polarisation Index, bar-to-bar surge test and Post-meggar check for test damage;
- Assess and repair the necessary rotor bandages and wedges, clean if necessary as indicated by Initial Test; retest and record the changing insulation condition and leakage;
- Final Test : Pre-meggar, AC Leakage Trend Test, DC Leakage Trend Test, Polarisation Index (P.I.), bar-to-bar surge test and Post-meggar check for test damage;
- Balance, assess bearing journal run-out, turn commutator and undercut correctly.

Central to this process was the understanding of the failure history previously studied in detail. As mentioned infantile failures of armatures recently reconditioned, revealed that many had initial LIR readings. However after cleaning and passing normal hi-potential testing during overhaul - failed in one of the prime electrical winding site areas listed above. It was found that a new series of tests were required to check these potential failure sites on the DC armature windings.

6.0 COMBINED AC, DC LEAKAGE AND P.I. TESTING AND RESULTS INTERPRETATION:

6.1 Test Procedure Development:

The original test procedure was developed over a number of years (originally developed from testing which QR had its contractors carry out on some problem main generators). OEM specifications generally only provide a single point Hi-potential test for DC and AC voltage tests. QR found that these tests were not satisfactory for assessment of repair success. As previously mentioned, many armatures after washing and drying (even if they came for LIR) would pass such a test. Investigation of the level of the test revealed a manufacturers concern of damaging the insulation system during electrical testing. QR, however, found with the Kapton/Nomex and Kapton/Mica Composite insulation systems will survive testing to elevated and sustained test voltage. No injury to the insulation of the armature windings occured - provided the Kapton was handled in a dust free environment and not damaged during coil formation (except where it cannot be avoided in the barrier repair required in the armature coil knuckle). Then, using the ability of the Kapton insulation to act as a capacitive film, the application of the AC Leakage Trend Test and Polarisation Index Test was first used to screen out armatures with poor insulation continuity. This was further developed into DC insulation trend testing.

DC Leakage Trend testing is in fact a 1.5 minute polarisation test carried out at 300 Volt Test intervals. The two test values of DC leakage are taken at an initial delay of 30 seconds, after reaching the test voltage, and then another subsequent delay of 120 seconds.

Using this test regime, and examining multiple test leakage curves, (the before and after banding/re-wedging repairs and washing under winding bandages), in conjunction with ductor and bar to bar surge testing has provided QR with the necessary means to assess the uncertain decision, as to when to repair (to reduce capital outlay) and when it is wise to rewind (to prevent heavy operational losses due to an armature earth fault in traffic). Figures 5 and 6 show normal DC and AC Leakage Trend curves for QR traction machine armatures. It is also to be noted that the P.I. should remain the same ($\pm$ 10%) or rise during repair. Figures 7 - 9 show a typical repair sequence for a D29 armature undergoing reconditioning. The initial DC Leakage Test shows that the armature has captive brush carbon under the NDE winding bandage (normally near the commutator riser). Currently QR is further investigating the subtle changes in the P.I. and the DC leakage curve during wedging and re-bandaging operations, as a means of checking for insulation cracking or stretching, but tabular data is not sufficient yet to confirm this.

6.2 Brief Test Theory Outline:

Using trend testing (P.I. and DC leakage), it is possible to see changes or discontinuities in the leakage of sum of the resistive ground current plus polarising current for the film insulation, compared to the sum of the subsequent resistive ground current plus the reducing polarising current}. This has proved useful in identifying trouble spots on the armature while it is being reconditioned. Narrowing between the curves normally indicates trapped carbon under a band or behind the riser, whereas good even spacing up to the mid range test voltage, then narrowing, has been found to indicate there is an insulation weakness where the coil exits one or other end of the core slot section. Discontinuities in the AC or DC curve slopes are indicators that the insulation system leakage versus voltage behaviour is changing suddenly, and it is worthwhile through further investigation of the armature insulation and windings, to find out why. This is particularly of interest if the change occurs at a voltage above traction system voltage - but within the range of the switching transients that occur on locomotives (due to protective control gear operation). It is theorised, that it is these high rate of rise spikes that actually damage the machines' insulation. (Note: Testing is carried out at 40 - 45 °Celsius).

6.3 Successes and Limitations:

To date QR uses this test technique to remove about an additional 60 armatures / annum (from about 900 repairs per year) to convert them to rewinds. This saves operational failure expenses, loss of locomotive utilisation and on repair scope (i.e. prevention of serious core damage and consequential stator damage).

Figure 5

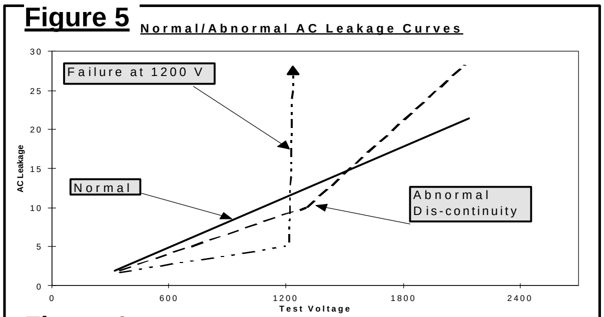
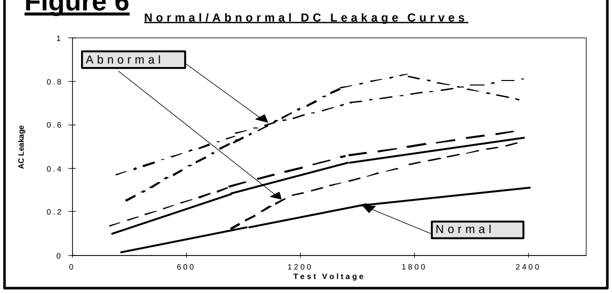
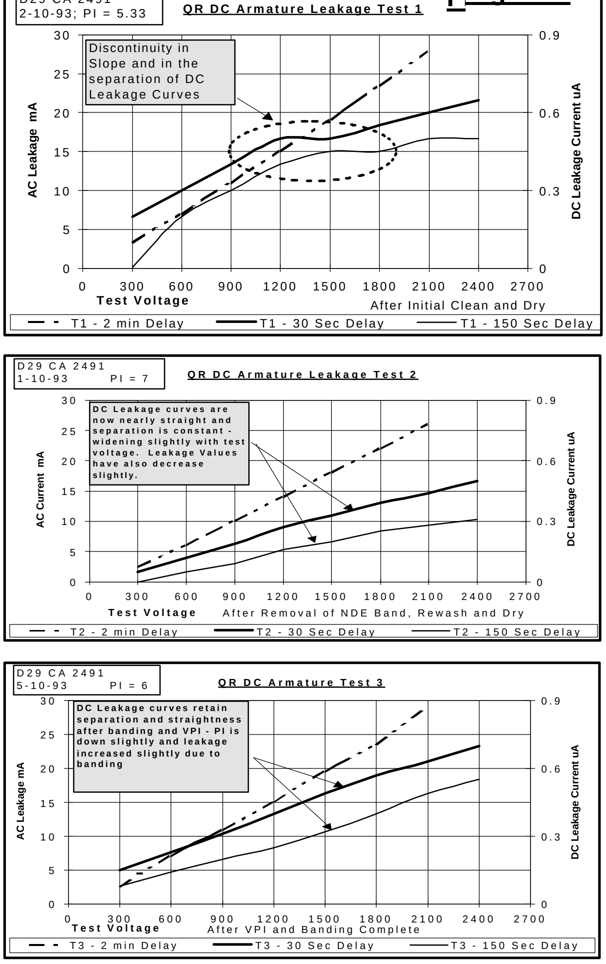


Figure 6



Similarly, such static testing will not screen out coil centrifugal and thermal movement related failures where poor banding and winding consolidation procedures, for multi-stack winding coils, have allowed inter-turn movement. Currently a form of no load testing (i.e. testing to maximum overspeed and thermal stress) is being considered as adjunct to these tests, as a final screen for an overhauled traction machine.

Figure 9



7.0 CONCLUSION

This test regime has proven highly successful for QR over the past five years, being initially driven from the commercial view point of preventing costly operational failures of traction machines. The benefits of this policy are now starting to be realised, however, it has been a long process. Such developments are highly dependent on a detailed knowledge of the motor insulation and coil structure. This process of developing non-intrusive test indicators of traction machines is now also being applied to the stator windings of the newer three-phase asynchronous traction machines now starting service in QR. This basis for cost effective maintenance and minimisation of operational failures within QR continues. There is ongoing research into the development of these indicators, and the training QR staff and contractors in testing for these indicators, and observing unusual machine behaviour and deviation from normal operation.