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ELectromagnetic Core Imperfection Detection (ELCID)
A Collection of Case Studies

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INTRODUCTION

The electromagnetic core lamination fault detection technique, now universally known as EL CID, was originally developed around 1980 by the then Central Electricity Generating Board (CEGB) in the UK to solve certain current test requirements on turbogenerators.

Since that time the technique has been used increasingly worldwide on generators and large motors. Details of the test theory and application are outlined in a paper by John Sutton (Reference 1) which also provides other references to the early work.

The other and long established method of testing the integrity of magnetic core laminations is by means of a high power loop or rated flux test, often referred to as a High Flux Ring test or various permutations of these words, carried out with the rotor of the generator removed. With the Ring Flux test the core is excited to or near to the full rated flux of core by means of a single phase high voltage winding through the bore and around the outside of the stator. The rated flux produces fault currents similar in level to those which flow when the generator is in operation and therefore in theory will also produce similar hot spots and temperature rises, subject to discrepancies resulting from different operating conditions such as inoperative cooling system, etc.

The EL CID test uses a similar excitation winding but at a very low flux level, typically four percent of rated flux. Hence the heat produced by faults is negligible and not detectable, but the fault current is detectable by electromagnetic means and it is this fault current, when scaled up to the appropriate rated flux level, which would give rise to the local generation of heat and associated hot spots.

There potentially exists therefore a small theoretical difference between the two methods associated with the assumed distribution of the heat produced. Although heat produced by the detected EL CID fault current, in conjunction with the test excitation voltage along the length of the fault, will be representative of the power dissipation to be expected in a Ring Flux test, the precise location of heat within the fault current loop is not defined. This difference is not normally of practical significance but may sometimes need to be considered when analysing changes in deep faults with complex fault current paths.

The two forms of tests may be considered complementary to some extent and the appropriate method will often be dictated by the prevailing circumstances. Advantageous features of EL CID testing are covered elsewhere, such as in Reference 2 referred to again below, and more recently the tendency to reduce major outages has given rise to EL CID tests being carried out without removal of the rotor, where Ring Flux tests are not possible.

Studies of the correlation between the test results of both methods provide a basis for confidence in EL CID test effectiveness itself and also for continued monitoring of earlier Ring Flux detected faults. A comprehensive comparative analysis of the test methods applied to turbogenerators was carried out and reported in 1985 by Shelton and Reichman in Reference 2.

Although the EL CID method has been readily adopted by many users for testing hydrogenerators for some time, a number of differences in the relative machine design compared with turbogenerators has given rise to reservations. This paper provides a collection of case studies designed to demonstrate the methods available for testing hydrogenerators where,

1. All poles have been removed but the rotor is still in position,
2. A few poles have been removed,
3. All poles are in place without any disassembly and,
4. Complete disassembly and testing with rotor removed.

Each technique will be described and, where available, correlation with loop test results will be shown.

Case Study #1

Station Name:	Ludington Pumped Storage Station
Location:	Ludington, Michigan, USA
Machine Owner:	Consumer's Energy
Unit Type:	325 MW; 20kV Hitachi
Test Performed:	Full Digital ELCID Inspection
Scope of Work:	Complete Generator Stator Rewind
Disassembly:	Removal of all salient poles (64)

In September of 1998 ADWEL International Ltd was contacted by Siemens Power Corporation to assist with three (3) complete ELCID inspections of Consumer Energy's Ludington Pumped Storage Station Unit #4. (See Figure 1.)

Figure 1. Exposed generator with weatherproof enclosure

This contract involved a unique circumstance in which the entire stator core was rewound *without* removal of the generator's rotor. Instead, all sixty-four (64) salient poles were removed in order to allow a crawl space for workers to complete the job. As is normally recommended, one ELCID test was to be performed prior to the removal of the original coils, another immediately following the coil removal, and one final test prior to the return to service of the machine. Due to limited access between the rotor housing and the stator core surface (approx. 12”) and a core length exceeding six feet (2.4m) it was determined that a robotic vehicle carrying a standard ELCID sense head (Chattock coil) would be best suited to the task.

The first test was performed in mid-September prior to the installation of a protective dome over the exposed generator. The poles had all been removed and full access to the space between core and rotor was allowed at both the top and bottom. As the top of the rotor had already been developed as a work area (Figure 2) the ELCID test was setup and run from this point. The equipment used for the testing was the Digital ELCID Model 601 and Robotic Inspection Vehicle RIV Model 701 as provided by ADWEL International Ltd.

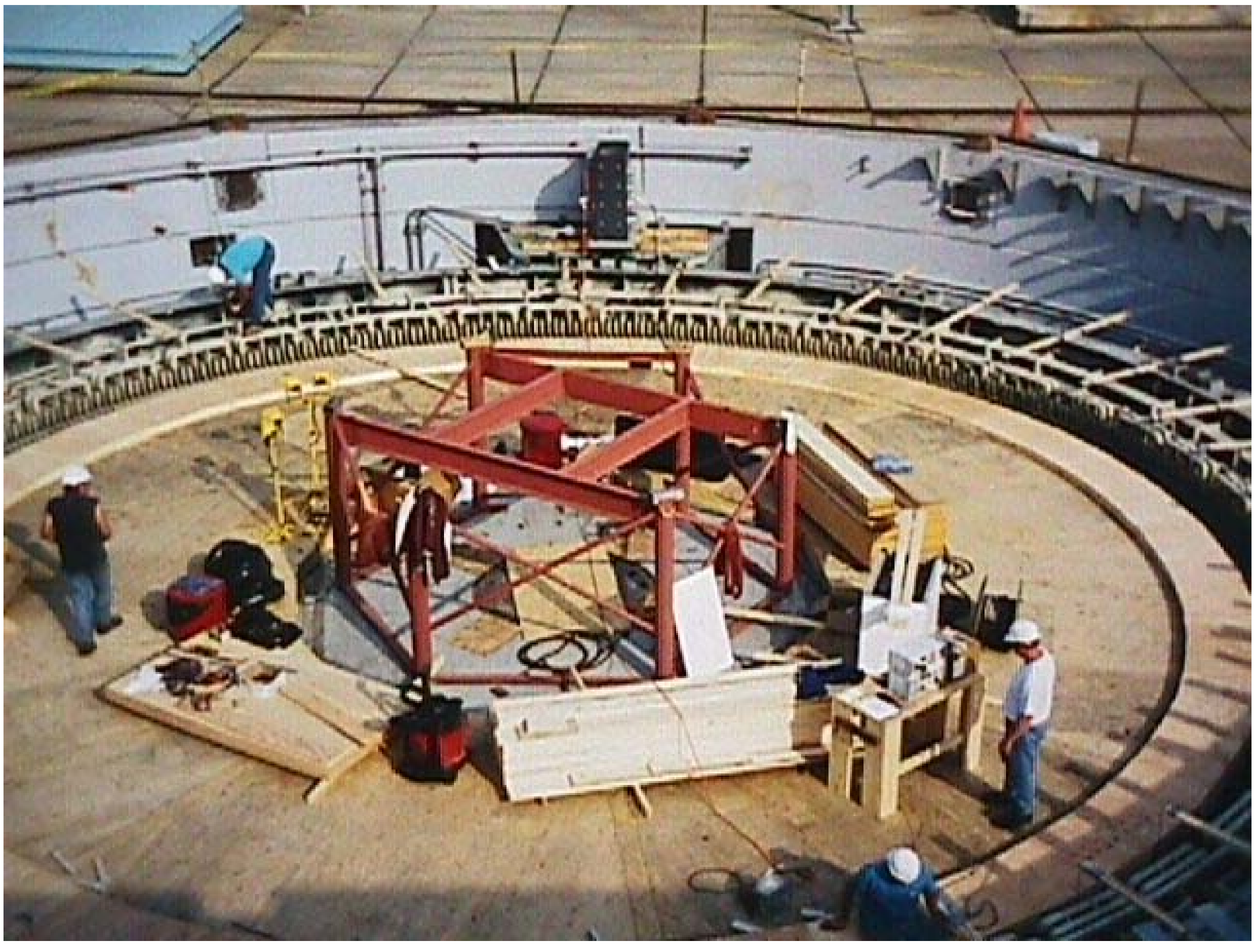

Figure 2. ELCID test setup and work platform

The core was excited using thirty-six (36) separate turns of standard 10 AWG stranded wire distributed evenly around the core circumference. As per standard procedure, the core was energized to approximately 4% of its rated flux density using a variable transformer that provided 23.6 amperes at 6.72 volts.

For the first test the robotic vehicle was set up with a sense head mounted in both the front and the back of the unit. A switching box enabled the operator to use one sense head for the downward pass of each slot and switch to the other Chattock coil for the return sweep of the same slot. As the robot was magnetically attached to the core surface it was manually positioned over each slot by the operator

(Figure 3), driven up and down each slot by remote control and then manually indexed to each consecutive slot (504 slots in total). Figure 4 shows the robot in one of its passes on a single slot (2nd test – coils removed).

Figure 3. Manual positioning and indexing of robotic vehicle

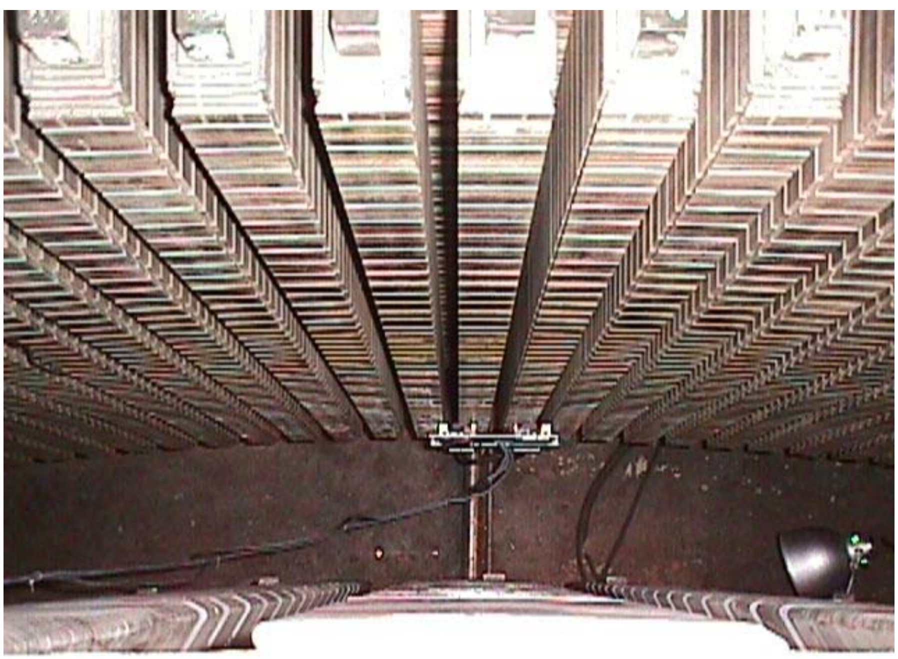

Figure 4. Robotic Inspection Vehicle traversing a single slot

With the robot in place the operator could continue the entire ELCID inspection of the core following the standard test procedure for a split core hydrogenerator. A paper by G.K. Ridley (Reference 3) provides more specific details on this procedure including that used for the six (6) core joints for this test.

Due to the large number of slots and the requirement for two additional tests it was decided to develop a test method to further decrease the time necessary to complete a full inspection. This was accomplished by developing a ramp for the robot that would act as an extension of the slot enabling the robot to scan one complete slot in a single pass. This was quickly manufactured on site and used for subsequent tests allowing testing time to be reduced from 8 hours to approximately 5 hours. Figure 5 illustrates the ramp that was used.

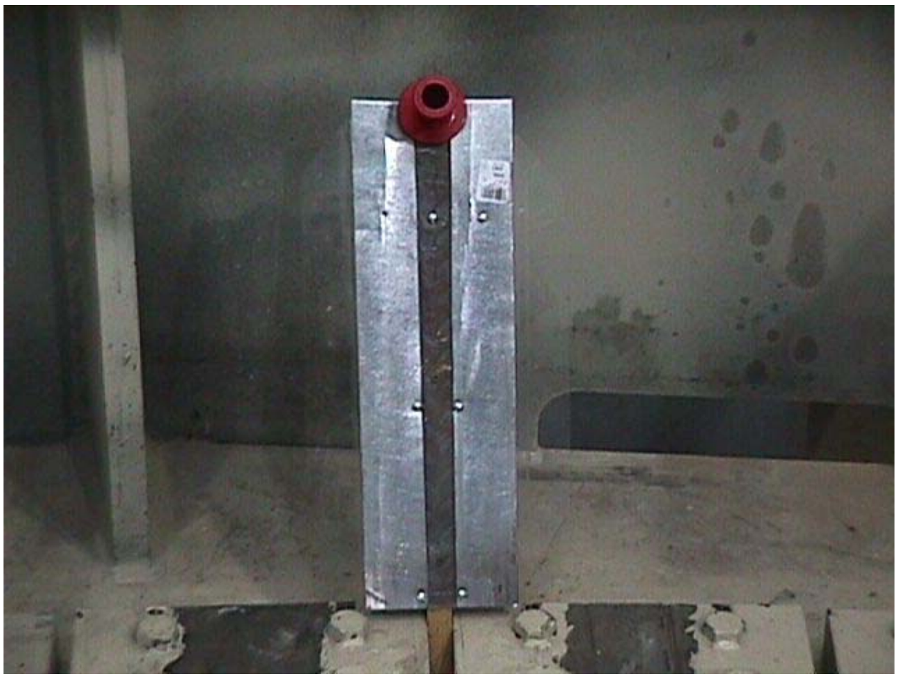

Figure 5. Ramp developed to extend stator slot for the robot

All three ELCID tests indicated a stator core in acceptable condition without existing or resultant damage from the rewind process. The core was rewound and returned to service with confidence in the integrity of the existing stator core iron. Each of the three remaining sister units will undergo this same procedure in the years to come.

Case Study #2

Station Name:	Chute a Caron
Location:	Jonquiere, Quebec, Canada
Machine Owner:	ALCAN
Unit Type:	50 MW; 13.2kV Westinghouse
Test Performed:	Partial Digital ELCID Inspection
Scope of Work:	Generator Inspection
Disassembly:	Removal of two (2) salient poles

In September of 1998, ADWEL International received a request from Westinghouse Canada of Burlington, Ontario to assist with a generator inspection at the Chute a Caron facility for ALCAN in Jonquiere, Quebec. Unit #4, a 1920's vintage Westinghouse unit (Figure 6) was to be shut down for a brief time to allow for visual inspection and determination of any future maintenance requirements.

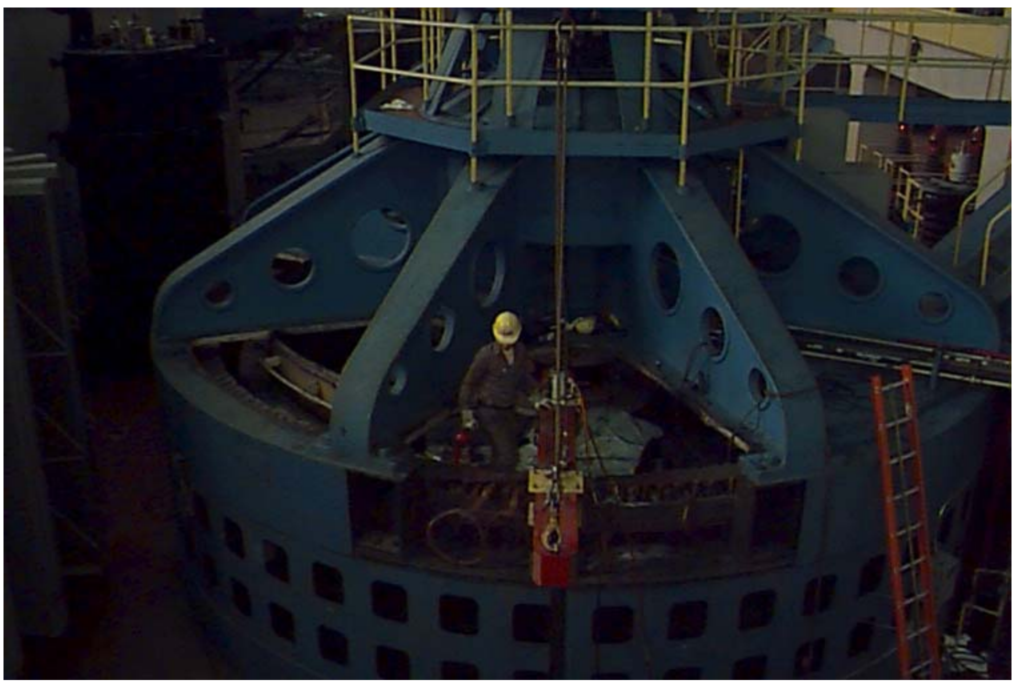

Figure 6. Unit #4 at ALCAN's Chute a Caron facility

Due to the nature of this outage and the time allotted, only minimal disassembly would be practical. The top plates were removed from the machine and two (2) adjacent pole pieces were removed. This made available a space approximately 10-12 inches wide and 36 inches in length. The workspace for this unit would have to be on top of the rotor under the main frame and the exciter housing as shown in Figure 7.

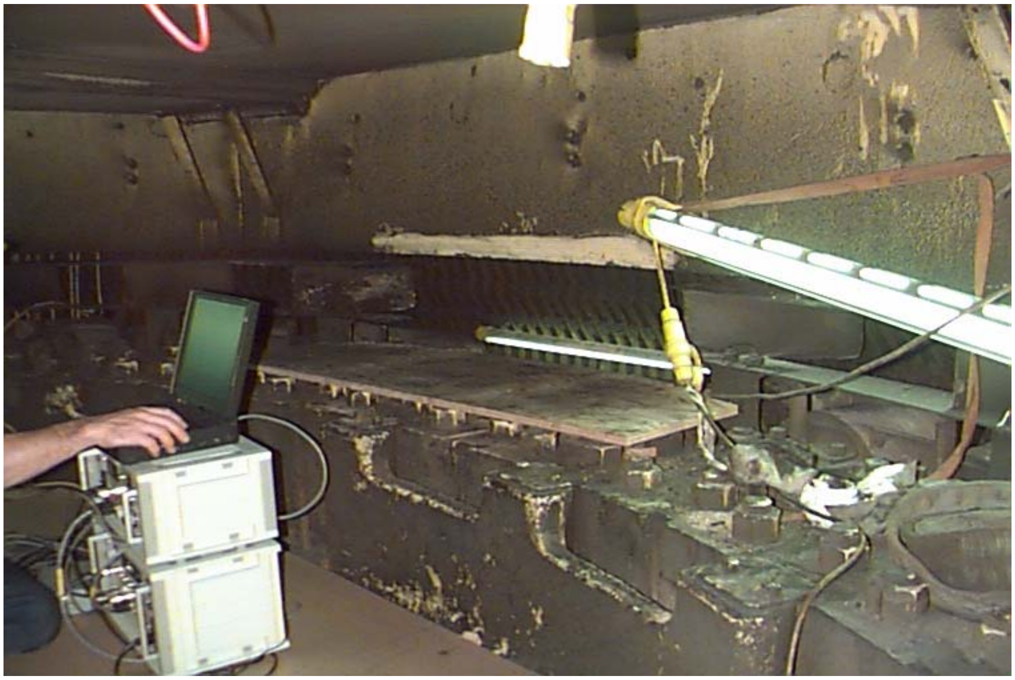

Figure 7. Available workspace on top of rotor body

This core was excited using twenty-eight (28) turns of 10 AWG cable that was distributed in four groups around the core circumference. A variable transformer capable of providing 20 amperes at 110 volts was used to achieve 4% excitation. Figure 8. Illustrates a single bundle of the excitation cabling.

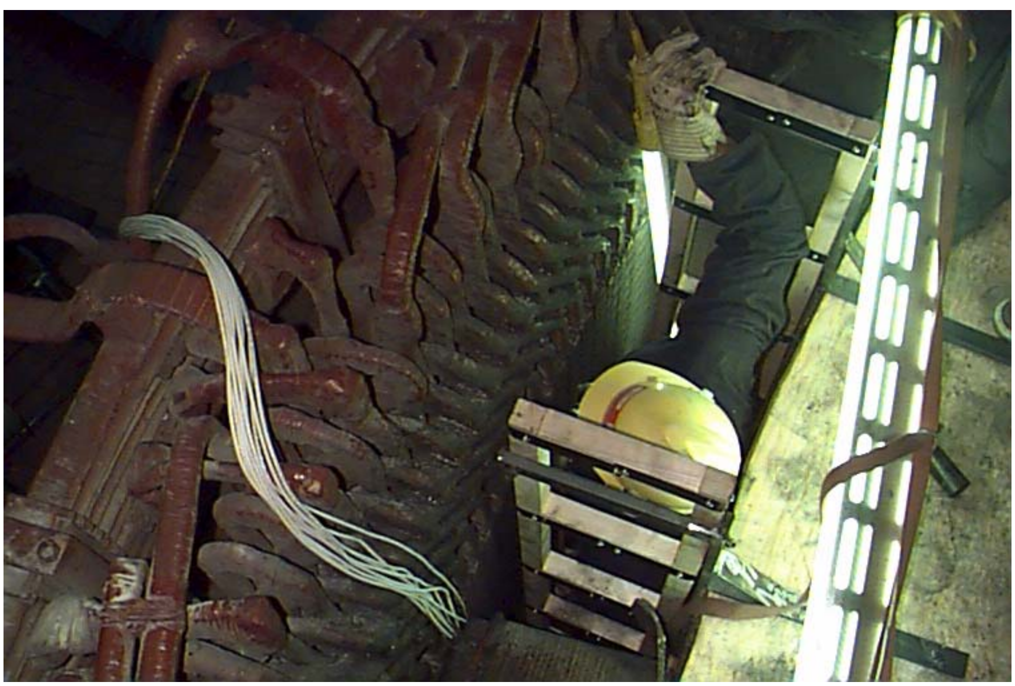

Figure 8. One of four bundles of excitation cable (7 turns)

With limited time available it was decided to perform the ELCID inspection on only selected areas of the core. The areas surrounding each of the four (4) core joint were chosen. Due to the absence of an oil pressure bearing the rotor would be indexed by using a cable and pulley arrangement in conjunction with the overhead crane. Again, using the Digital ELCID and the RIV Model 701 inspection vehicle the operator would have ample space to launch the vehicle in each of the selected areas. A dual sense head approach was used in this case with a Chattock coil mounted in the front and back of the robot for a complete scan of the slot with two passes of the vehicle. Removal of two pole pieces allowed access to approximately 12-14 slots at each location. Figure 9 shows the robot traversing a single slot in one of these locations.

Figure 9. Robotic Vehicle with dual chattock coils traversing a single slot

As this was an open-air ventilated machine in operation for a number of years there was a significant build up of dirt and grease on the core's inner diameter. This, however, did not prove to be an issue for the magnetically-attached, tractor-driven robotic vehicle. Each area was scanned and the rotor indexed to the next location in less than 8 hours. It is conceivable that given sufficient time, the entire stator could be evaluated in this manner. Sufficient information was collected, however, to increase the owner's confidence in continuing to operate the machine until a more thorough investigation could be properly scheduled.

Case Study #3

Station Name:	Waldeck
Location:	Germany
Machine Owner:	Prusen Electric
Unit Type:	300 MW; 15.75 kV AEG
Test Performed:	Complete Digital ELCID Inspection
Scope of Work:	Generator Inspection
Disassembly:	None

In this instance the generator was a 300 MW AEG pumped storage unit which operated as a motor and a generator. The generator had 300 slots and was rated at 15.75 kV. The utility involved required an inspection as a sister unit had shown significant core problems when it had been examined with a loop test following its removal from site. An ELCID test would allow the utility to avoid the delays that had occurred with the first unit.

This test proved to be particularly challenging because the airgap was only 42mm (Figure 10) and at the time the only robot available had a height profile of 42mm. Access to the core was only possible from the top and due to the construction of the machine there was a restricted working area.

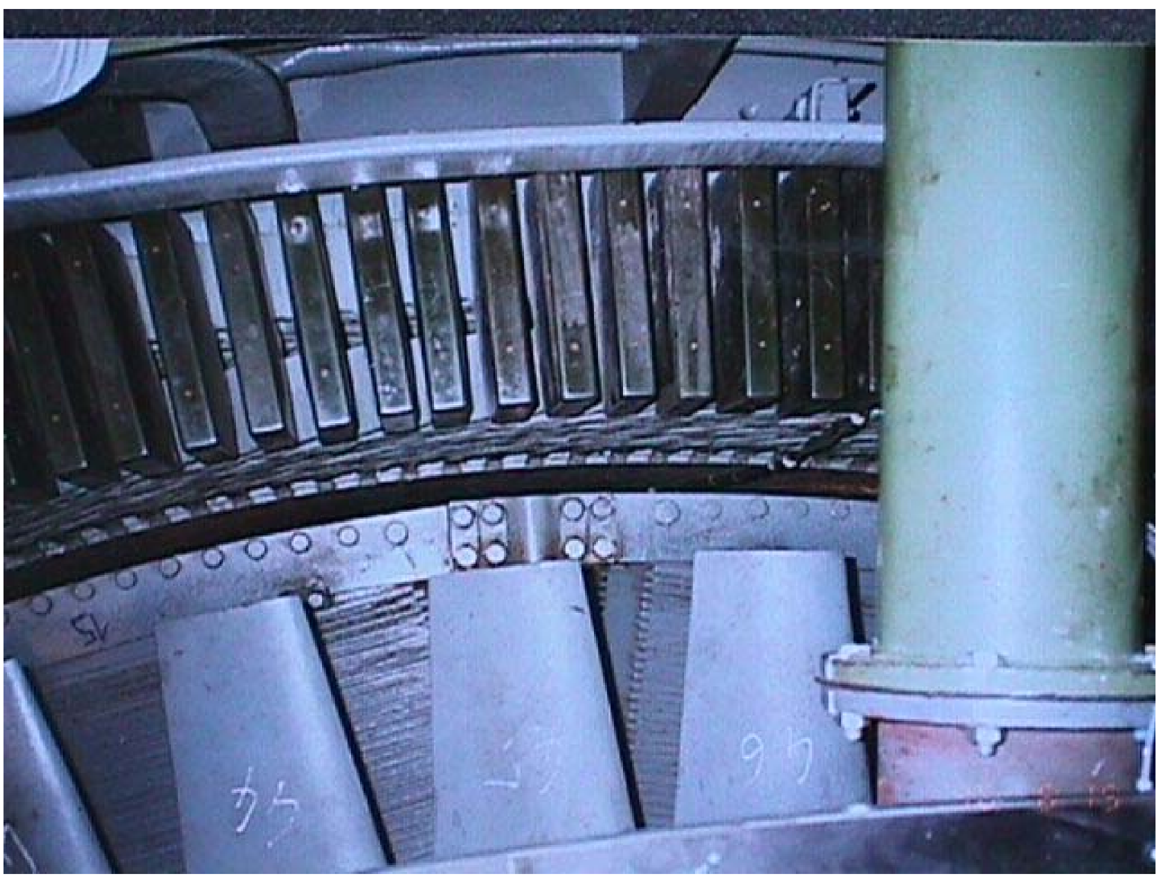

Figure 10. Air gap at Waldek

To enable the robot to enter the air gap the covers of the robot were removed and cardboard covers put in place. Figure 11 illustrates the robot with the covers removed prior to being launched in the air gap.

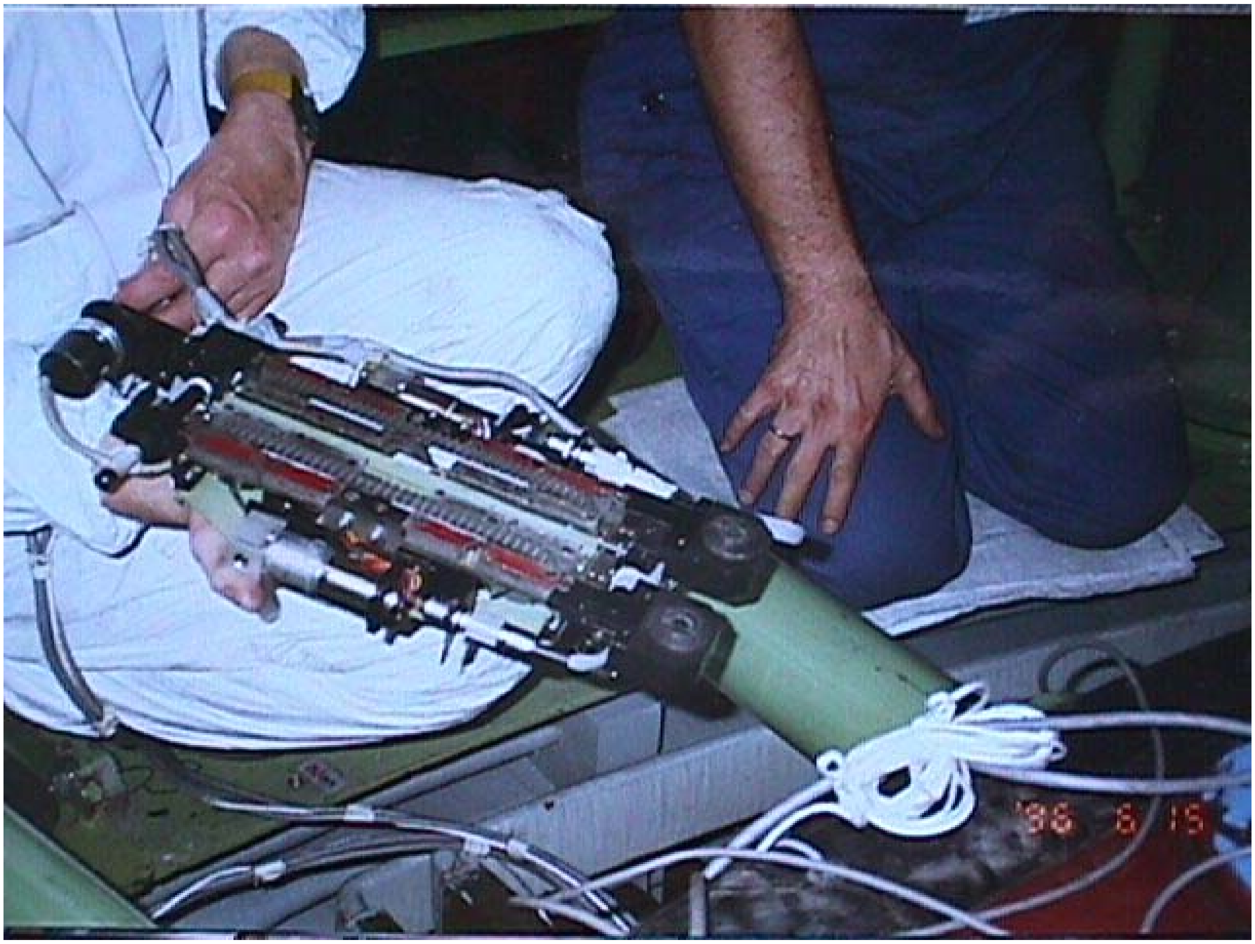

Figure 11. Robotic Inspection Vehicle – Covers removed

At this time the robot only had the capability for mounting a single flat Chattock at one end. This meant that the test had to effectively be repeated twice due to the untested length of core under the robot. As the previous case studies have shown, the robot today is only 30 mm high and has two Chattock holders one at each end. The test was a slow process, as the vehicle had to be passed down and then up the slot before being removed and then lowered to cover the next slot. Experience has since been gained using a system to index the robotic vehicle from slot to slot without removal from the airgap. Figure 12 captures the robot as it proceeds down one of the 300 slots.

Figure 12. Robotic Vehicle in place to scan a single slot

Two 12 hr. shifts were required to complete the test. Results were unambiguous and showed that no serious faults existed. Figure 13 show a sample of the results collected.

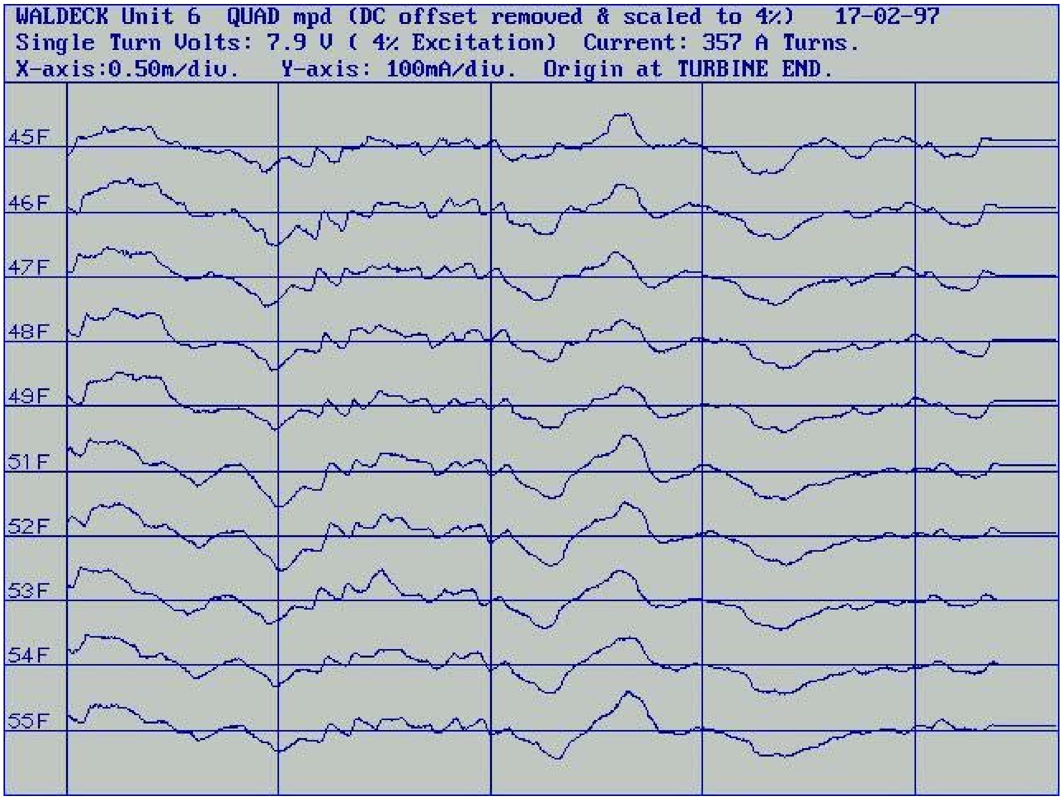

Figure 13. Sample ELCID results from Waldeck

The core was eventually removed and tested with both ELCID and high-powered loop test to verify the results. The ELCID results were very reproducible. The loop test showed no serious problems but highlighted a number of short faults, which gave a temperature rise of 5°C above ambient. The utility chose to have some repair work done although the core could easily have been put back into service without any repairs being done.

Case Study #4

Station Name:	Brownlee Unit #4
Location:	Idaho,USA
Machine Owner:	Idaho Power Company
Unit Type:	99 MW; 13.8kV Westinghouse
Test Performed:	Full Digital ELCID Inspection
Scope of Work:	Complete Rewind
Disassembly:	Complete Removal of Rotor

In November of 1999, ADWEL International received a request from Idaho Power company to perform an ELCID inspection on Unit #4 at the Brownlee Generating Station in Western Idaho. They had scheduled a major outage for one of their hydro-electric generators in order to perform a partial rewind of damaged coils. Although high potential and insulation resistance tests had shown acceptable results, removal of existing coils indicated substantial bar vibration damage. With a spare set of coils in stock, a decision was made to rewind the unit.

A routine ELCID test was planned to confirm the acceptable condition of the stator core. An initial ELCID global scan, however, indicated a core with numerous surface and slot faults of various magnitudes (Figure 14). A subsequent high flux test (loop test) confirmed above ambient heating as a result of slot and surface damage most likely caused by excessive bar vibration. A sample of the damaged areas and the resultant increase in core temperature is shown in Figure 15.

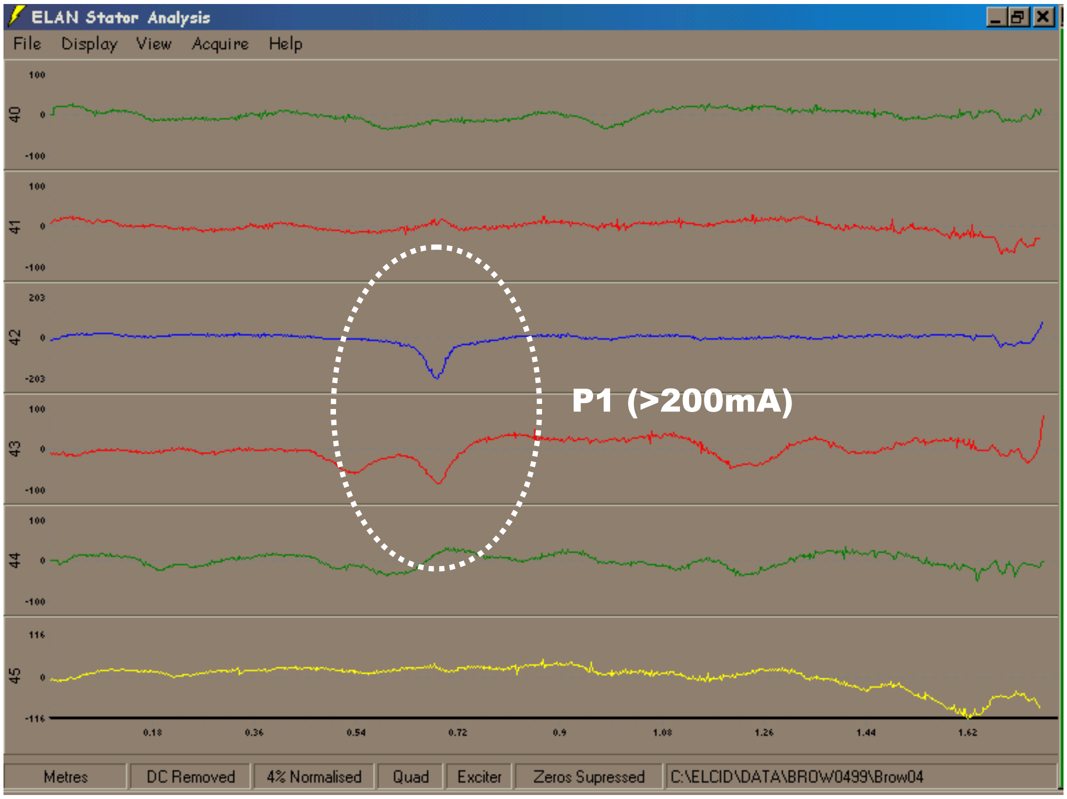

Figure 14. ELCID values exceeding 200mA at Point Labeled P1 (Slots 42/43)

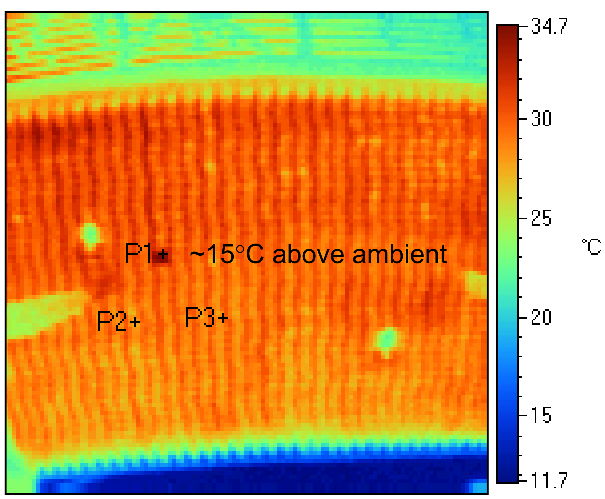

Figure 15. Loop Test result for Slot 42/43 showing >15°C temperature rise

After considerable repair efforts and one final ELCID inspection to confirm the effectiveness of repairs, the utility was able to salvage the existing stator core, install new coils, and return the unit to service.

Case Study #5

Station Name:	Shawinigan 2 Powerhouse
Location:	Shawinigan, Quebec, Canada
Machine Owner:	Hydro-Quebec
Unit Type:	40 MW; 11kV Westinghouse
Test Performed:	Partial Digital ELCID Inspection
Scope of Work:	Uprate and Refurbish
Disassembly:	Removal of Rotor

In October 1997, GE Canada, Hydro division, signed a contract with Hydro-Quebec to refurbish five horizontal hydro-generators at the Shawinigan 2 powerhouse. The Shawinigan 2 station, located in the Province of Quebec, Canada, houses 8 units built from 1912 to 1952. Three were built in the early 1950's by Canadian General Electric and are rated at 40 MVA, 11kV. The remaining five were constructed between 1912 and 1914 by Westinghouse Company and are coupled to two I.P. Morris horizontal Francis type turbines. Hydro-Quebec plans to uprate these five horizontal units from 15MVA, 6.9kV to 17 MVA, 11kV. The contract began with Units 4 and 5, scheduled to be rewound by the end of 1998.

In order to determine the remaining operational life of the cores without the presence of any historical data, a decision was made to conduct a full flux ring test (loop test) in conjunction with an ELCID test on both units 4 and 5. Both inspections would be conducted with the original winding in place. Visually the cores displayed no major surface damage. The customer assumed the cores to be original with the exception of a partial re-stack conducted in the mid 1960's during a full rewind. This assumption would place the cores for Units 4 and 5 at 84 and 83 years old respectively. GE Canada subcontracted the manufacturer of the ELCID equipment, ADWEL International Ltd of Toronto, Ontario, Canada to assist in the ELCID analysis of the cores. This also presented an opportunity to correlate the effectiveness of the two test methods. The following is a brief account of the test results and the actions taken for Unit 5.

The loop test was performed one day prior to the ELCID test. The stator core was energized to a flux level of 0.835 Tesla and held for 45 to 60 minutes. Several locations were identified where the temperature was 5OC above the average core temperature. As an example, one area of slot 157 indicated a temperature rise of 15OC after 60 minutes. Figure 16 displays the thermographic image of that slot.

Figure 16. Thermographic Image for Slot 157 Damage

The following day an ELCID test was conducted using the Digital ELCID-Model 601. The core was energized to 4% of its rated flux density using an excitation system of 20 series connected turns of 10AWG wire and a current of 24 amps. Indications corresponding to the previously located thermal hot spots were found for each of the damaged areas. Figure 17 illustrates the ELCID trace for slot 157. The fault current indicated greatly exceeds any acceptance criteria.

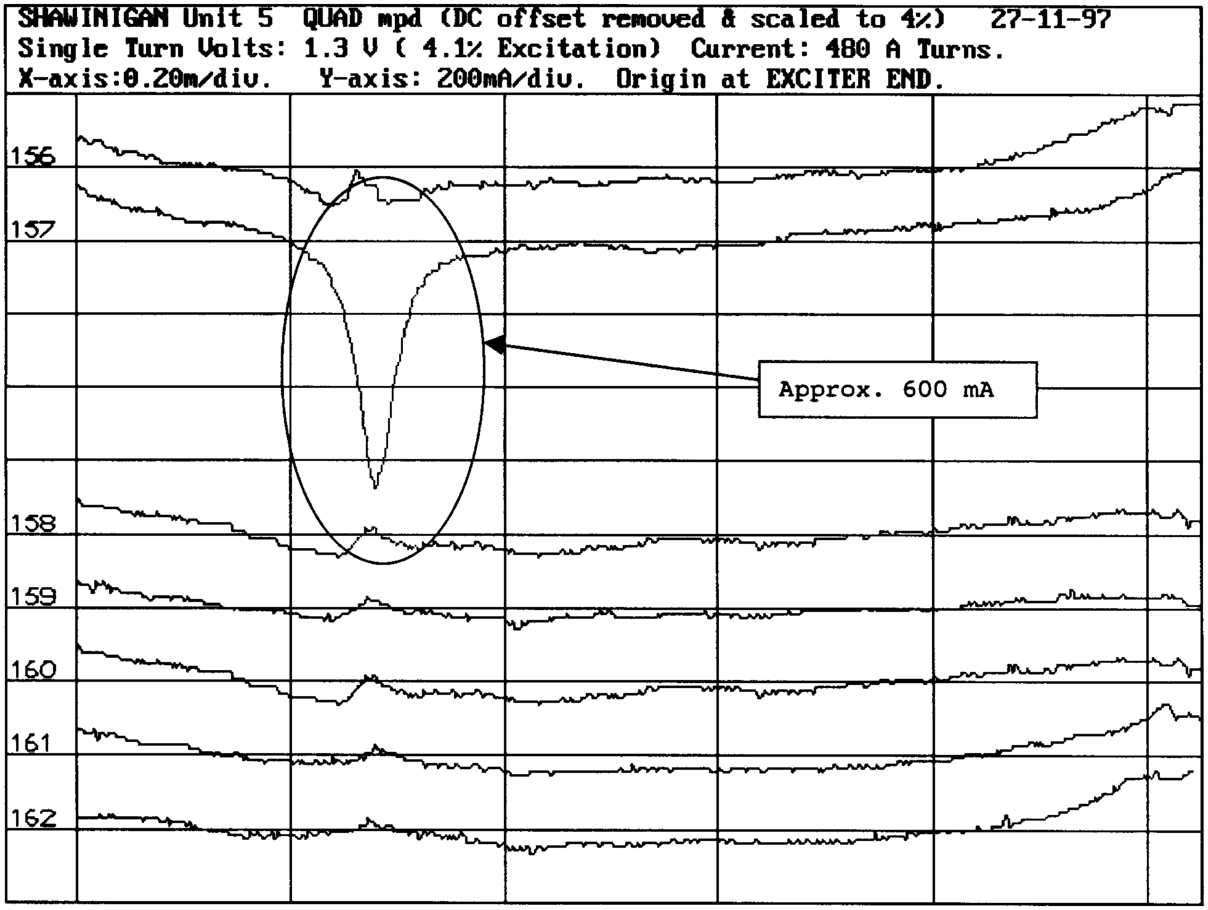

Figure 17. 600mA ELCID Indication for Slot 157

Based on the indications of both tests and the age of the core the customer decided to completely replace the core iron. Prior to completely removing the old core, the damaged areas were visually located. Figure 18 shows the damage found at slot 157. It was determined that the damage was caused by a coil groundwall fault which fused about 35 laminations located about 320mm from the exciter end of the core and 20mm below the core surface.

Figure 18. Visual Confirmation of Damaged Area

In order to develop a database, GE Hydro continues to apply the ELCID method in addition to the conventional full flux ring test. This data will provide useful correlation between core faults measured in mA with the ELCID test and the expected real temperature rise at full flux density. ADWEL International Ltd continues to support the development and application of the ELCID technology to hydrogenerators worldwide.

CONCLUSION

The ELCID test technique has been demonstrated to be an effective method of detecting a variety of stator core iron faults in a variety of maintenance situations. When used as an alternative to, or in conjunction with the Ring Flux Test, the ELCID method provides a safe, low power solution for determining the condition of a laminated stator core.

ACKNOWLEDGEMENTS

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AUTHOR

Brad McNamara (P. Eng.) received a Bachelor of Electrical Engineering degree from the Technical University of Nova Scotia (TUNS) in 1990. Prior to joining ADWEL International in 1995 he worked with Litton Systems Ltd. as a test and development engineer in the design of military automated test instrumentation systems.