

## **EXPERIENCE AND BENEFIT OF USING EL-CID FOR TURBINE-GENERATORS**

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G. Klempner  
Ontario Hydro

### **Abstract**

Ontario Hydro has experienced numerous stator core problems over the years and has attained a great deal of expertise in locating, characterizing and repairing core faults. Until the relatively recent introduction of the El-CID (Electromagnetic - Core Imperfection Detector) test, the method used for core fault detection was the Flux test. This method is costly and time consuming to perform and also dangerous by its very nature.

In the early days of the Flux test, stator core temperature measurements were made by placing thermocouples in strategic locations and by reaching into the core and feeling for hot spots. Later on, the use of infra-red systems greatly improved the Flux test since the entire stator bore could be scanned for hot spots from outside the bore. The actual temperatures could now be read remotely, in addition to having a photographic view of the core hot spots.

However, in an effort to devise a safer, low power method of detecting core faults that could be done in far less time and lower cost than Flux testing, the El-CID test was developed.

Ontario Hydro purchased an El-CID test set in early 1986 and performed its first test at Nanticoke Thermal Generating Station in July of the same year. Since that time over eighty El-CID tests have now been carried out. El-CID has been so successful that Ontario Hydro has even performed the test for numerous generator manufacturers and for most of the other utilities across Canada.

The focus of the discussion in this paper is the experience and benefit that El-CID has provided to Ontario Hydro by use on its own and in conjunction with Flux testing. Three core fault investigations and their results are presented to show how the El-CID is used by Ontario Hydro and the level of reliability that is now perceived.

It is Ontario Hydro's opinion that El-CID is a reliable test method for detecting the existence of core faults and locating them in the stator bore. El-CID has been used on several occasions to reliably locate core faults or interlaminar insulation deterioration and to verify successful repairs. However, the El-CID test alone has not always been sufficient to characterize core faults. Flux testing is still required in many situations to assist in core testing and defect characterization and locating.

## **Introduction**

The EI-CID technique was devised in the U.K. by the Central Electricity Research Laboratories and developed by Adwel Industries as portable test equipment for rotating machines. Since inception, EI-CID has proven to be universal in its application, covering turbine generators, hydraulic generators and large motors.

Traditionally, stator core interlaminar insulation testing has been done using the Flux test method, in which rated or near rated flux is induced in the stator core yoke. This test induces circulating currents in the stator core laminations and excessive heating in areas where the core interlaminar insulation is damaged or shorted. The heat produced is detected and quantified using established infra-red techniques. This method has proven to be successful over the years but requires a large power source and considerable time, manpower and resources to complete.

In recent years, the EI-CID test was developed as an alternative to the Flux test. The technique is based on the detection of core faults directly in the damaged areas of the core at only three to five percent of rated flux. Further, the test requires usually only two people to complete in one eight hour shift.

EI-CID has proven to be reliable in the detection and locating of core problems and can cut the time and manpower requirements for core testing by as much as ninety percent. With more recent experience, EI-CID has now been used on numerous occasions to reliably determine the severity of core faults or interlaminar insulation deterioration and to verify repairs to some faults. This has not always been, and is still not always, the case though. There is significant amount of judgment involved, to determine when the EI-CID is properly predicting the severity core insulation damage, and requires an experienced operator to know the difference. A Flux test is still often required, to determine if repairs are needed, the nature of the repair and subsequently the success of any repairs carried out.

## **EI-CID Test Procedure**

The EI-CID test is done with the rotor removed, although there are now variations of the EI-CID test which have been developed to perform the test with the rotor installed. This involves an EI-CID sensor head adapted to a crawler device which traverses the air gap.

The excitation level for the EI-CID test is determined by a combination of the stator design parameters and the power supply available to achieve the required flux level. For most large generators, the standard 120 V AC outlet with a current carrying capacity of 15 amps is adequate.

The characteristics of most stators are such that 4 to 7 turns of #10 AWG insulated wire are generally used. The energized winding will produce approximately 4 percent of rated flux at 5 volts per meter across the stator iron. A powerstat or variac is used for excitation control. In Canada, the supply is 120 V AC at the source. The excitation current is measured from the source and is usually less than 15 amps and depends on the number of turns used.

The signal processing unit of the EI-CID test equipment measures fault current in mA. By theory and experimentation as outlined in the EI-CID manual by the manufacturer, a measurement of at least plus or minus 100 mA is required, at 5 volts per meter on the core, before it is considered that the core has significant damage that would affect the interlaminar insulation.

The excitation winding and power supply are set-up as shown in Figure 1. The EI-CID equipment (Figure 2) is set up as shown in Figure 3. The sensor head is pulled axially along the core at a speed slower than one meter every two seconds and always touching and bridging two stator teeth. The reference coil is placed in the bore over undamaged iron also as shown.

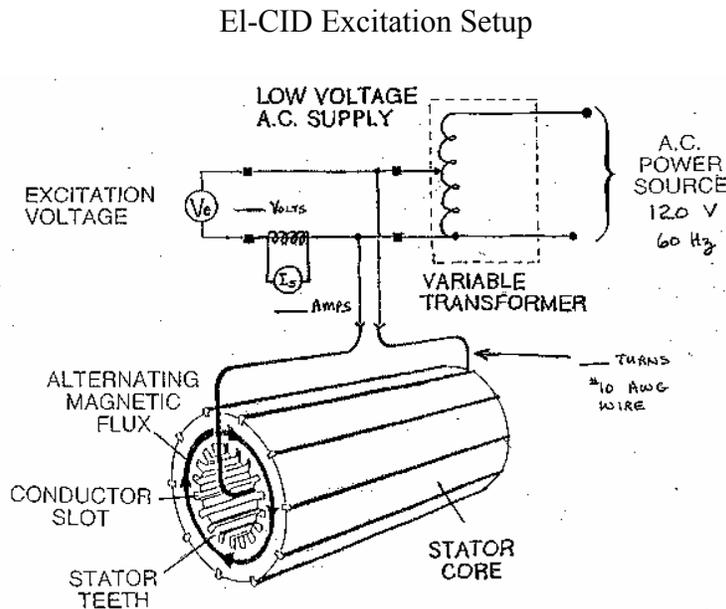


Figure 1

The Basic EI-CID Test Equipment Used by Ontario Hydro



Figure 2

The fault current signal is read directly off the signal processor meter and/or it can be output to an XY plotter. When the reference coil and sensor head are both over undamaged iron, the meter should read zero since it is calibrated before testing for a condition where no fault current is circulating. In actual practice, no insulation system is perfect and some fluctuating background signal is usually detected.

EI-CID Equipment Setup

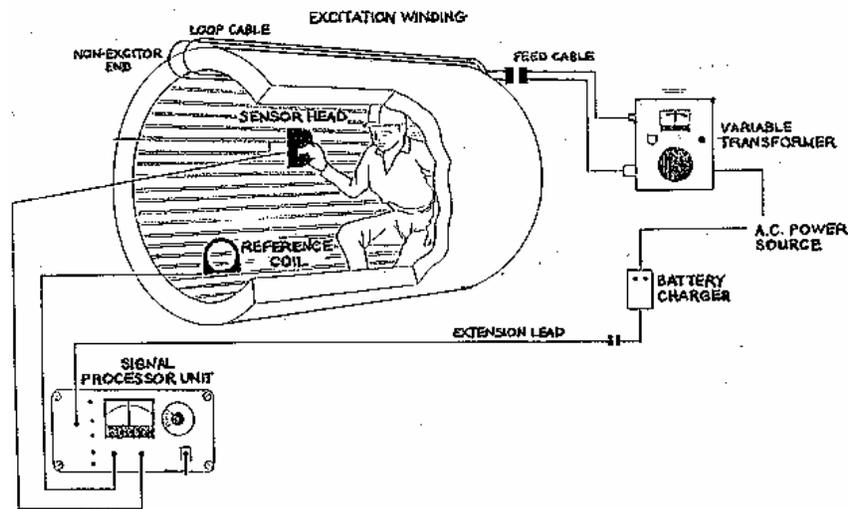


Figure 3

In the EI-CID test, when the sensor head is placed over damaged core areas, the fault current is read directly and proportionally, in "Quadrature" mode, as the differential between the sensor and the reference. This is indicated on the signal processor meter.

Ontario Hydro also uses the "Phase" mode readings when faults are detected, to try and characterize the type of fault found. Experience with the EI-CID test has shown that in "Phase" mode, a fault area only produces the M.P.D. (Magnetic Potential Difference) signal level due to the excitation applied when there is deteriorated, aged or fretted insulation. Solid interlaminar shorts or where there is iron damage, tends to produce very high signals in "Phase" mode.

### Flux Test Procedure

The basic premise on which the Flux test is based is to also excite the stator core iron, but to as near rated flux as possible and monitor the temperature rises of the core in the stator bore. The iron will slowly heat up on good core material and can be recorded as the ambient core temperature rise. Where there is damaged or deteriorated core insulation, the core will overheat and is detected as a hot spot above core ambient due to high fault currents circulating locally.

The Flux test is also done with the rotor removed. The excitation level is determined by a combination of the stator design parameters and the power supply available to achieve near rated flux. Ontario Hydro generally accomplishes this using two phases of a 4 KV breaker since this is

usually the only suitable power supply available with high enough voltage and current carrying capacity.

The characteristics of most stators are such that 5 to 7 turns of 500 to 750 MCM insulated cable are generally used. When the winding is energized, the flux level produced is almost always in the range of 75 to 90 percent of rated flux.

Ground fault and overcurrent protection are installed for safety. Supply voltage, supply current and flux volts per turn are measured. Since there is no voltage control, when using a breaker directly, a remote trip switch is connected for immediate shut down capability should a core overheating problem occur.

The core temperatures and hot spot rises are monitored and recorded using infra-red systems from outside the stator looking into the stator bore directly and into a rotating, moveable, mirror with non-reflecting glass. A mirror at a 45 degree angle is used to obtain accurate temperature measurements since the reflective and emissivity properties of a mirror with non-reflecting glass are known. The mirror and general Flux test set up is as shown in Figure 4.

Flux Test Set-Up on a Nanticoke TGS Generator Stator

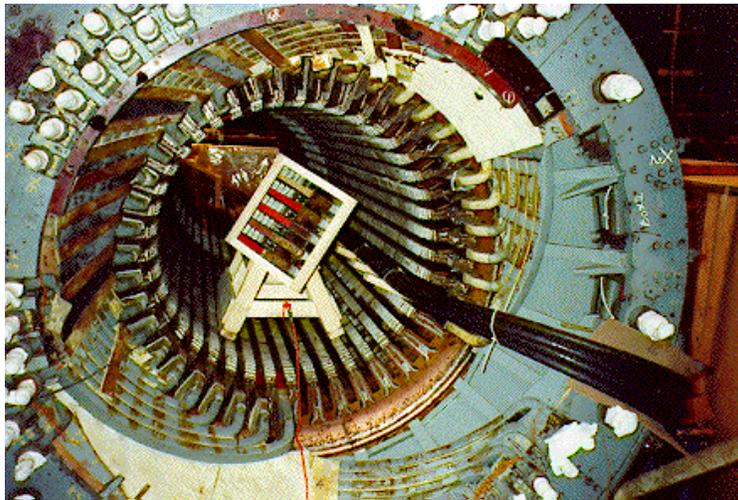


Figure 4

Direct viewing of the core, on an angle from outside the stator, causes errors due to changes in core reflective properties as the viewing angle changes. The emissivity of the surface being measured must be known and this changes with lighting effects during angled viewing. Therefore, temperatures cannot be accurately determined by scanning the core surface at an angle.

The general temperature rise of good core areas are measured as well as any hot spot detected. The hot spots are compared to the ambient core temperature over time to produce a temperature rise relationship. Where there is damaged or deteriorated core insulation, the core overheats and

is detected as a hot spot above core ambient due to locally circulating high currents in the damaged area. Ontario Hydro considers hot spots less than 5°C above core ambient with slow temperature rise at the same rate as the core ambient rise to be the acceptance criteria. Under extreme circumstances, 15°C stabilized rises have been accepted when all attempts at core repairs can produce no better result and the operation of the unit is critical.

#### Thermographic Views with Isotherms Included on a Four Pole Generator Stator

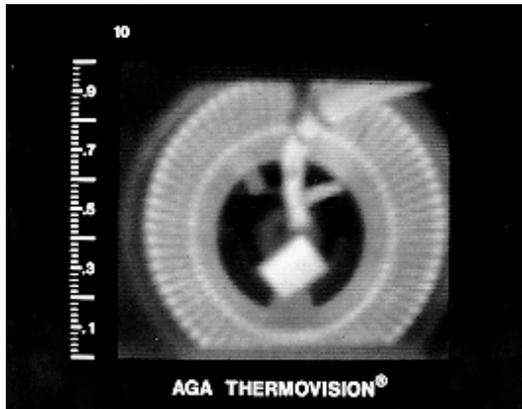


Figure 5

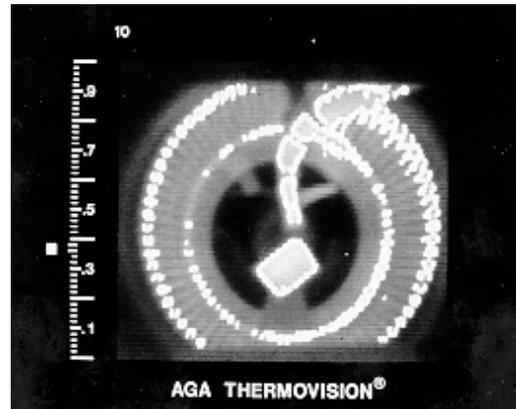


Figure 6

Figure 5 is a thermographic view of the bore of a four pole stator with the excitation winding and rotating mirror installed. Figure 6 shows the same view with the thermographic isothermal level now visible. The hot spot areas and general good core areas in the view are located with the infra-red system's isotherm function and the isotherm level recorded on the vertical scale at the left. The temperatures of the isothermed areas are then calculated based on the isotherm level measured, a reference measurement and the ambient air temperature. In the particular example shown here, the thermography was done by an AGA Thermovision System 750. Newer systems can now produce outputs as temperature values directly, and show the delta temperature from one area to another in varying degrees of colour.

#### Lakeview TGS - Unit #6 Experience

In March 1990, an EI-CID test was performed on Ontario Hydro's Unit #6 generator at Lakeview TGS, as part of a generator rehabilitation program. This machine is a 300 MW, 2 pole, 60 Hz, tandem compound generator. During the EI-CID test, two significant readings were recorded that indicated possible stator iron faults of severe enough nature to warrant repair.

The general signal levels recorded over the majority of this stator were in the 0 to +/-20 mA range with some scattered readings up to 40 mA. These readings are considered satisfactory at an excitation level of 5 V/m on the core. The two defect locations produced EI-CID measurements of +270 and +350 mA, indicating some problem with the interlaminar insulation condition.

The first indication was located on the 3rd core packet in from the exciter end of the generator, on the tooth between slots 34 and 35. Since the reading across slot 34 was high at +270 mA, and

the reading across slot 35 was near normal, it was estimated that the fault was at or near the top of the tooth, on the side nearest slot 34. See Figure 7.

The second indication was located on the 12th core packet in from the exciter end of the generator, on the tooth between slots 18 and 19. The reading across slot 18 was high at +350 mA. The reading across slot 19 was also high at +100 mA but was near normal across slot 17. Therefore, it was estimated that the fault was at or near the top of the tooth between slots 18 and 19, but more on the slot 18 side of the tooth. See Figure 8.

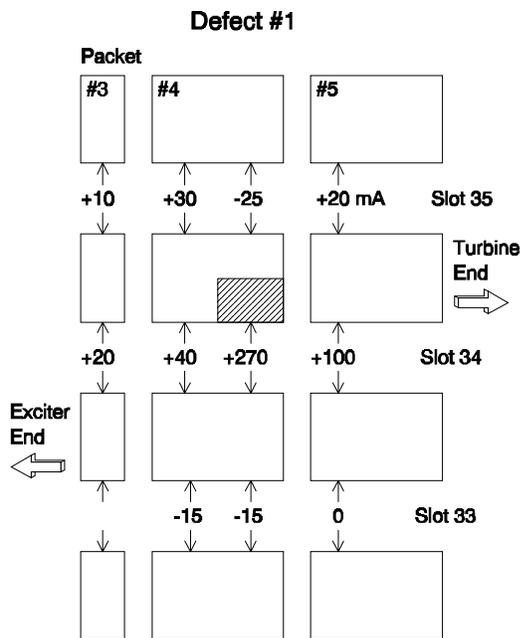


Figure 7

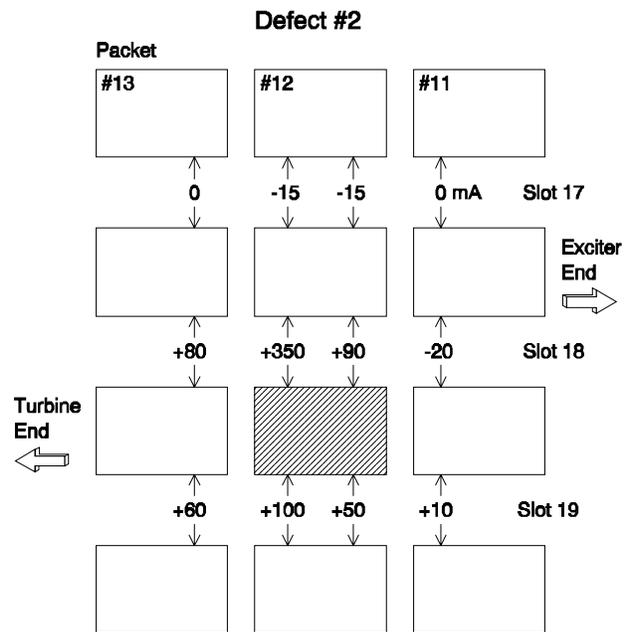


Figure 8

The faults were estimated to be near the top of the tooth by local scanning with El-CID flex head probes and over a substantial portion of the tooth top. In addition, the same measurements above were made in the “Phase” mode of the El-CID signal processing unit and showed levels no higher than the M.P.D. due to excitation. Therefore, it was estimated that the damage found was likely due to insulation deterioration rather than solid interlaminar iron damage. As stated previously, iron damage has been found to produce “Phase” readings over the fault area, several times the M.P.D. level.

Although significant El-CID signal levels were recorded, both defect locations did not show any visible signs of damage. Therefore, to verify the existence of the defects, a Flux test with infra-red scan was also performed.

The Flux test was carried out using 7 turns of 500 MCM cable connected to two phases of a 4 KV breaker. Ground fault and overcurrent protection were installed for safety. Supply voltage and current were measured at 4427.5 V AC and 464.76 amps. The flux volts per turn were measured at 608 V AC using a separate single turn winding connected to a step down

transformer. This produced Flux test at 87.7% of rated. The core temperatures and hot spot rises were observed and recorded using an AGA Thermovision System 750.

The Flux test was performed over a 50 minute period and indeed confirmed the presence and location of the two defects found by EI-CID testing.

The first defect on the 3rd core tooth packet between slots 34 and 35 produced a temperature rise of 33.8°C above core ambient at 15 minutes into the test. The fault temperature then stabilized to a constant temperature rise of 34.5°C above core ambient for the remainder of the test. The fact that the hot spot showed up immediately and produced a rapid rise time and stabilization, supported the EI-CID conclusion that the fault was near the iron surface. See Figure 9.

The second defect on the 12th core tooth packet between slots 18 and 19 produced a stabilized temperature rise of 36.5°C above core ambient also by approximately 15 minutes into the test. The fault temperature remained fairly stabilized at this level above core ambient for the remainder of the test. Again, the fact that the hot spot showed up immediately and produced a rapid rise time and stabilization, supported the EI-CID conclusion that the fault was near the iron surface. See Figure 9.

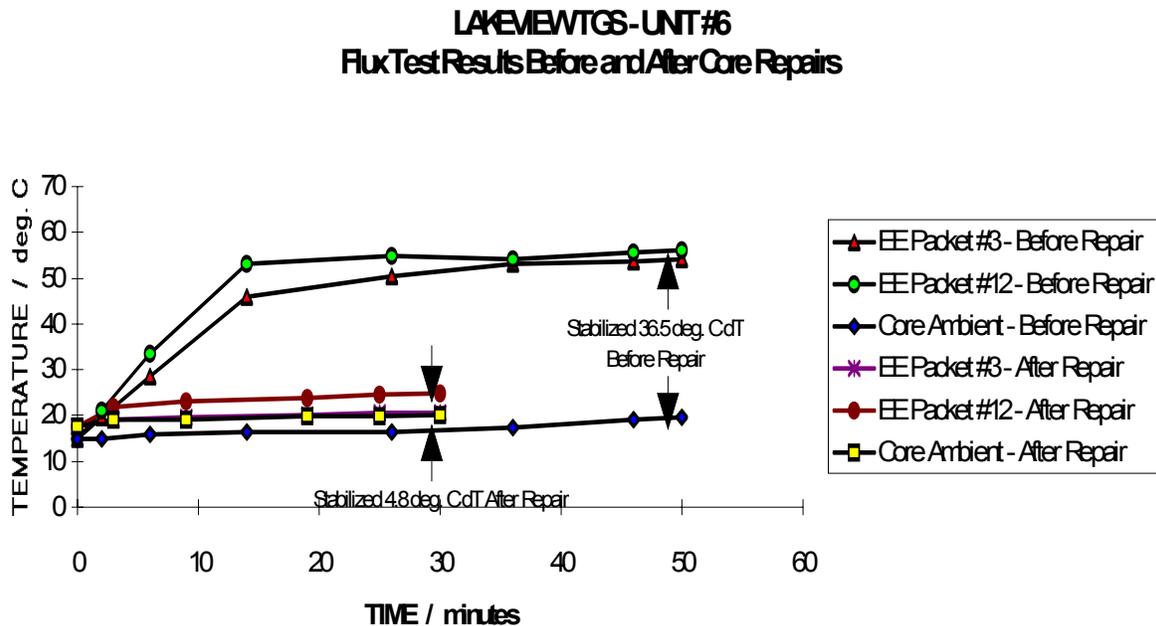


Figure 9

Repair of both faults were carried out by localized grinding down of the tooth tops of both core packets by approximately 1/4". The tooth tops were then electro-etched with a 20% phosphoric acid solution to ensure separation of the laminations and that insulation could be detected to remain between all adjacent laminations on the tooth.

A second EI-CID test (at identical excitation levels) was performed, which produced signal levels over the fault areas of no more than 40 mA. A successful repair was indicated.

To further confirm the repairs and verify the EI-CID results, a second Flux test (also at identical excitation levels) was performed. The Flux test showed temperature rises on both fault locations of now only 4.8°C after 30 minutes. See Figure 9. Therefore, Ontario Hydro's criteria of no hot spots above 5°C was met and the damage to the stator iron was considered repaired.

Finishing of the defect repair was completed by an application of a suitable penetrating/insulating epoxy.

The experience gained with this type of observed fault has, on two additional occasions, allowed Ontario Hydro to find core defects with the EI-CID test, repair the damage and confirm a successful repair without the need for a Flux test.

### Nanticoke TGS - Stator #4301 Experience

The Nanticoke generators are 2 pole, 60 Hz machines rated at 500 MW. Generator stator #4301 at Nanticoke TGS has been installed in the Unit 4 position in past and is presently in the Unit 8 position. This stator has a long history of stator winding and core problems but has served to increase our understanding of the EI-CID technique, due to the extensive testing done by both EI-CID and Flux methods, and the subsequent repair work. This discussion covers some of the comparison work done between EI-CID and Flux tests, before and after core repairs.

After a winding failure on this stator in August 1989 and an inspection of the stator iron, it was noticed that there were a number of 1st packets on the exciter end of the stator, around the bore circumference, that had visible damage. The core iron was found to be loose on a number of these 1st packets at the core end, and the insulation obviously worn away on some. An EI-CID test confirmed the damage in the areas indicated, but that the rest of the core was found defect free.

#### Thermography of the Defects on Nanticoke TGS Stator #4301

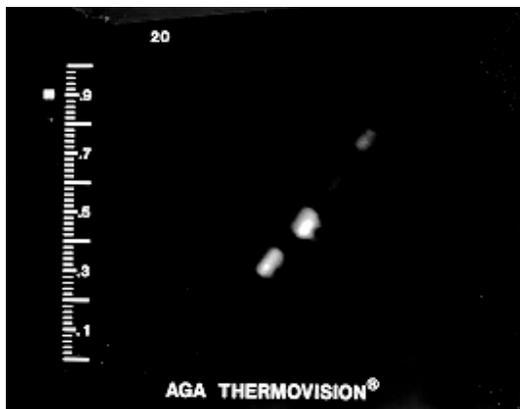


Figure 10

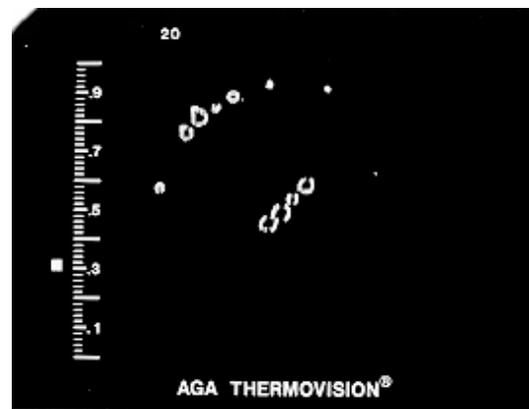


Figure 11

To determine the severity of the damage, a Flux test was also done to compare results. In fact, the Flux test results verified the location of the faults and that the remainder of the core was indeed free of damage. Figure 10 shows a thermographic close-up view, in the rotating mirror, of some of the worst defects. Figure 11 is an isotherm view of a number of defects, viewed both directly on the core end and of their image in the mirror.

The Flux test went further to allow comparison of temperature readings to the EI-CID signal levels recorded. The co-relation was good since the general trend showed that, the higher the EI-CID reading, the higher the temperature measurement for the same fault location. Figure 12.

Nanticoke TGS - Stator #4301 - EI-CID and Flux Test Data

| Slot # | Tooth | Before Core Repair |        | After Core Repair |        | Outage | Slot # | Tooth | Before Core Repair |        | After Core Repair |        | Outage |
|--------|-------|--------------------|--------|-------------------|--------|--------|--------|-------|--------------------|--------|-------------------|--------|--------|
|        |       | EI-CID             | Flux   | EI-CID            | Flux   | EI-CID |        |       | EI-CID             | Flux   | EI-CID            | Flux   | EI-CID |
|        |       | mA                 | deg. C | mA                | deg. C | mA     |        |       | mA                 | deg. C | mA                | deg. C | mA     |
| 1      |       | 70                 |        | 95                |        | 120    | 22     |       | -5                 |        | 80                |        | 65     |
|        | 1-2   |                    |        |                   |        |        |        | 22-23 |                    |        |                   |        |        |
| 2      |       | -85                |        | -90               |        | -135   | 23     |       | -40                |        | 0                 |        | -20    |
|        | 2-3   |                    |        |                   |        |        |        | 23-24 |                    |        |                   |        |        |
| 3      |       | 35                 |        | 45                |        | 100    | 24     |       | -25                |        | -40               |        | -35    |
|        | 3-4   |                    |        |                   |        |        |        | 24-25 |                    |        |                   |        |        |
| 4      |       | 70                 |        | 50                |        | 85     | 25     |       | 30                 |        | 50                |        | 40     |
|        | 4-5   |                    | 22.5   |                   | 13.0   |        |        | 25-26 |                    | 8.9    |                   |        |        |
| 5      |       | 190                |        | 150               |        | 90     | 26     |       | 35                 |        | 20                |        | 25     |
|        | 5-6   |                    | 15.8   |                   |        |        |        | 26-27 |                    |        |                   |        |        |
| 6      |       | -45                |        | -40               |        | -40    | 27     |       | -55                |        | -55               |        | -25    |
|        | 6-7   |                    |        |                   |        |        |        | 27-28 |                    |        |                   |        |        |
| 7      |       | -45                |        | -10               |        | -30    | 28     |       | -30                |        | -80               |        | -30    |
|        | 7-8   |                    |        |                   |        |        |        | 28-29 |                    |        |                   |        |        |
| 8      |       | -60                |        | -35               |        | -50    | 29     |       | -25                |        | 40                |        | 75     |
|        | 8-9   |                    |        |                   |        |        |        | 29-30 |                    | 8.4    |                   |        |        |
| 9      |       | -75                |        | -45               |        | -40    | 30     |       | 10                 |        | 35                |        | 80     |
|        | 9-10  |                    |        |                   |        |        |        | 30-31 |                    |        |                   |        |        |
| 10     |       | -30                |        | 15                |        | -30    | 31     |       | 85                 |        | -5                |        | 55     |
|        | 10-11 |                    |        |                   |        |        |        | 31-32 |                    | 16.0   |                   |        |        |
| 11     |       | 80                 |        | 50                |        | 70     | 32     |       | 140                |        | 130               |        | 175    |
|        | 11-12 |                    |        |                   |        |        |        | 32-33 |                    | 17.0   |                   | 7.3    |        |
| 12     |       | 145                |        | 135               |        | 55     | 33     |       | 200                |        | 130               |        | 145    |
|        | 12-13 |                    | 14.1   |                   |        |        |        | 33-34 |                    | na     |                   |        |        |
| 13     |       | -30                |        | 50                |        | -15    | 34     |       | 95                 |        | 0                 |        | 100    |
|        | 13-14 |                    |        |                   |        |        |        | 34-35 |                    | na     |                   |        |        |
| 14     |       | -40                |        | -40               |        | -45    | 35     |       | 90                 |        | 75                |        | 70     |
|        | 14-15 |                    |        |                   |        |        |        | 35-36 |                    | 21.3   |                   | 8.4    |        |
| 15     |       | -50                |        | -45               |        | -50    | 36     |       | 115                |        | 190               |        | 130    |
|        | 15-16 |                    |        |                   |        |        |        | 36-37 |                    | 21.2   |                   | 7.8    |        |
| 16     |       | -40                |        | -35               |        | -50    | 37     |       | -15                |        | 0                 |        | 30     |
|        | 16-17 |                    |        |                   |        |        |        | 37-38 |                    | 7.9    |                   |        |        |
| 17     |       | -10                |        | 40                |        | 25     | 38     |       | 150                |        | 50                |        | 95     |
|        | 17-18 |                    |        |                   |        |        |        | 38-39 |                    | 28.6   |                   | 14.8   |        |
| 18     |       | 15                 |        | 20                |        | 10     | 39     |       | 360                |        | 220               |        | 350    |
|        | 18-19 |                    |        |                   |        |        |        | 39-40 |                    | 21.3   |                   | 15.0   |        |
| 19     |       | -40                |        | -30               |        | -30    | 40     |       | 55                 |        | 80                |        | 145    |
|        | 19-20 |                    |        |                   |        |        |        | 40-41 |                    | 11.0   |                   |        |        |
| 20     |       | -5                 |        | 5                 |        | 10     | 41     |       | 115                |        | 140               |        | 150    |
|        | 20-21 |                    |        |                   |        |        |        | 41-42 |                    | 25.6   |                   | 11.1   |        |
| 21     |       | 0                  |        | 70                |        | 35     | 42     |       | 40                 |        | 35                |        | 30     |
|        | 21-22 |                    |        |                   |        |        |        | 42-1  |                    | 5.8    |                   |        |        |

Figure 12

The core damage was then repaired by inserting thin pieces of mica between the loose laminations, soaking the area with a penetrating/insulating epoxy and then re-tightening by driving a 1/16" G10 glass stemming piece radially into the center of the 1st core packet. See Figure 13. The result was the re-establishment of insulation between core laminations and tightening of the core end iron to reduce the possibility of further fretting in service.

#### Repaired Damage at the Exciter End of the Core - 1st Packets

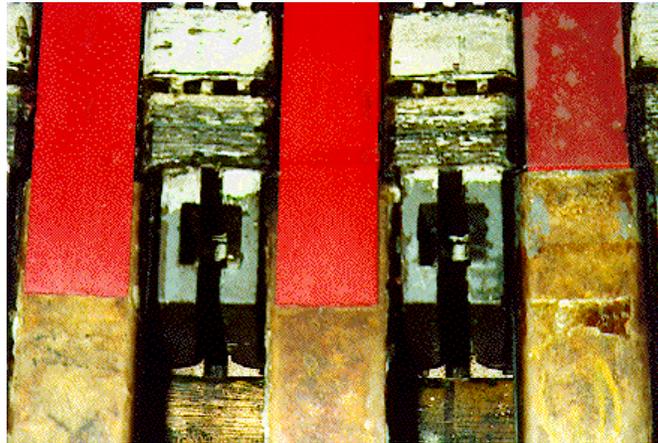


Figure 13

The repairs made were extensive and were the best that could be done without very expensive restacking of the stator core. The core tightness on the teeth was re-established as best as possible but was and is still regarded as a local repair and is not considered a substitute for re-pressing of the core.

The EI-CID and Flux tests were repeated at the same excitation levels as the tests prior to repairing the damage. These results are also shown in Figure 12.

Both the EI-CID and Flux tests confirmed that the repairs had been marginally successful, but the Flux test proved to be the most convincing. Each hot spot recorded by Flux test showed a reduced temperature after repairs. On the EI-CID test however, a few of the readings stayed the same or even slightly increased.

The reasoning at the time was that there was still interlaminar contact further down the tooth that was aggravated by tightening of the iron. Therefore, EI-CID was thought to be picking up signals due to this but that the interlaminar contact was not sufficient to generate hot spots that would show up on the infra-red. Some uncertainty in the EI-CID readings remained. However, the main damage had obviously been at the tooth tops and seemed to be alleviated by the repairs.

The repaired stator was placed back in service in Unit 8. The known damaged areas on the exciter end 1st packets were expected to fret again and it was planned to check them again at the next available opportunity after the stator had logged significant operating time.

Three and one half years later there was a short outage taken on the unit. The generator was opened up and the rotor removed. Visibly there was no observable increase in damage and the core seemed to have retained its tightness. A Flux test was not done at the time due to scheduling constraints, but because of the minimal effort required, an EI-CID test was carried out.

The test results showed that generally, the EI-CID signals had increased back up to the levels that were obtained before the core had been repaired. It is Ontario Hydro's expectation that this core will fail at some time due to a stator ground fault from the overheated core iron damaging the stator winding insulation of an adjacent conductor bar. The station has a spare stator and will make a component exchange should a failure occur.

Although there is high confidence that the EI-CID test is providing a true representation of the level of interlaminar insulation deterioration, another Flux test would be extremely beneficial in relating the EI-CID mA signals to actual temperatures. This will be especially true should the EI-CID levels become significantly higher than they have been before on this stator. It is intended to carry out further EI-CID and Flux testing at the next available outage opportunity or when a failure occurs.

### **Bruce B - Unit #7 Experience**

The Bruce B generators are 4 pole, 60 Hz machines rated at 900 MW. During a warranty survey on the Unit 7 generator in April 1988, after only 17,000 operating hours, a core defect was found by EI-CID testing. The entire core was tested and no readings were found greater than 10 mA except for the single defect location which produced an EI-CID signal level of +600 mA.

The defect signal was found to be across slot 41 on the 24th core packet in from the exciter end of the generator. A complete EI-CID signal profile of the fault area was made and is shown in Figure 14. The significant points to notice on the fault map are the low readings across slots 40 and 42 which tend to indicate that the fault is deeper down in the slot. In addition, the signal across slot 40 is the same polarity as the main defect signal while the signal across slot 42 is the opposite polarity. This suggests that the defect is most likely on the side of the tooth in slot 41, but on the tooth adjacent to slot 40.

Additional readings were taken with a smaller EI-CID flex head probe to try to determine the depth of the fault. Figure 15 is a map of the readings taken and the results. The significance of these results are that the readings also tend to indicate that the fault is not near the top of the stator tooth but rather farther down the slot. It is our speculation that the fault is most likely near the bottom of the slot next to the bottom conductor bar.

In addition to this, the main defect signal was checked in "Phase" mode to try and characterize the fault further. It was found that the signal was 2200 mA. The M.P.D. for the excitation applied is only 280 mA. Therefore, it was suspected that the fault has very good interlaminar contact, perhaps due to some iron damage, and that it is not simply deteriorated insulation. This would occur if the core iron had been smudged or damaged somehow in slot before or during installation of the stator bars.

Visually, the stator iron looked in perfect condition, and intrascoping of the radial cooling vents around the core packet indicated the same.

Standard Results of EI-CID Tests #1 and Test #2

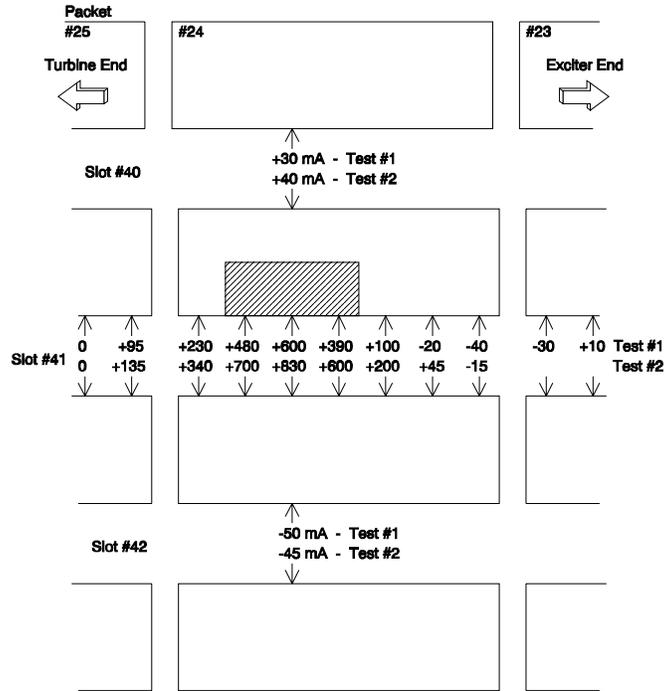


Figure 14

Results of Localized Scan of Fault Area with Flex Head - Test #1 and Test #2

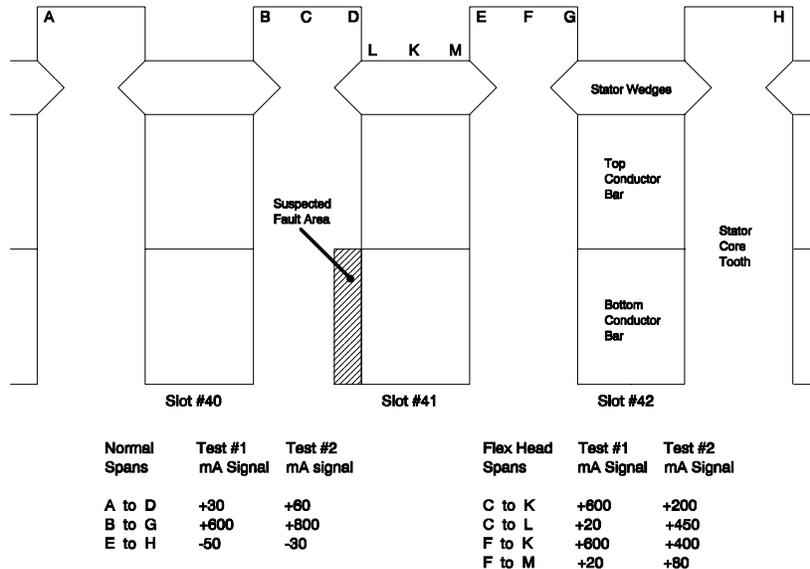


Figure 15

Since the generator was fairly new, there was considerable concern that the EI-CID test may not be correct. Therefore, a 75% rated Flux test was done and the core scanned for hot spots with an Agema infra-red system. The defect location was confirmed and is shown in a thermographic view in Figure 16.

#### Thermography of the Defects on the Bruce B Unit 7 Stator

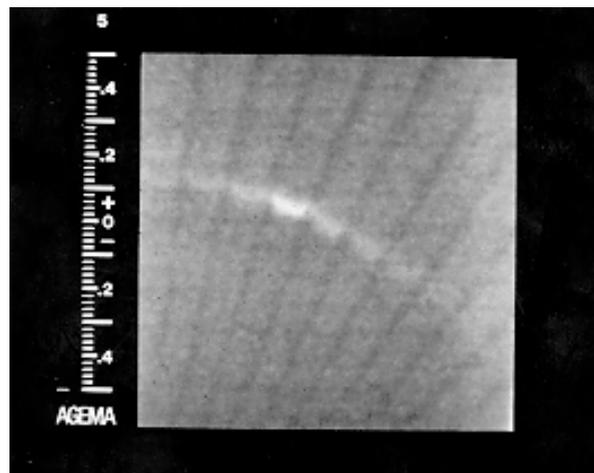


Figure 16

The Flux test produced a very slowly rising ambient core temperature and a very slow rising fault temperature that only reached 5°C above the rest of the core after one hour. The test was run for an additional 2 hours and the temperature rise only reached 8°C above the rest of the core. This type of information tends to confirm that the defect is likely deeper in the slot, relatively small, highly localized, and probably in the infant stages. Therefore, the unit was returned to service with the intent to inspect again in about three years.

In April 1991, Unit 7 was shut down again and the generator opened up for a maintenance outage. The generator had logged approximately 39,000 operating hours up to this point.

Another EI-CID test on the stator core was carried out to examine the core for advancement of the known defect. This EI-CID test was carried out exactly the same as the previous test done during the Warranty Outage when the defect was first found. The general signal readings obtained during this test were 0-10 mA indicating the stator core interlaminar insulation to be in good condition.

However, the defect location across slot 41, on packet 24 in from the exciter end of the machine, now recorded an increased EI-CID signal level to +830 mA in the exact location of the original that was found to be +600 mA. All other adjacent readings increased as well. See Figure 14 above.

Additional readings were again taken with a smaller El-CID flex head probe to fully characterize the fault. Figure 15 above also shows the results of this second test. The signals recorded were now higher in the more localized shorter measurement spans. The significance of this is uncertain but it was thought at the time that the insulation now may be becoming heat affected, causing the interlaminar insulation near the fault to be deteriorated over a larger surface area. Speculation was still high that the main fault is near the bottom of the slot next to the bottom conductor bar.

The main defect signal was again checked in “Phase” mode, and found to still be at 2200 mA, indicating no change in this respect. This may mean that if there is an iron smudge, that its size is unchanged and the increase in “Quad” mode signal is due to interlaminar insulation deterioration.

A 75 percent rated Flux test was performed again to both verify the El-CID results and to determine the extent of progression of the damage in the known defect location across slot 41. The result of the Flux test was that the defect location only produced a 4 degrees C rise in temperature as compared to good core areas after a one and a half hour test. Therefore, although the El-CID test shows the defect to be worsening, the Flux test indicated that it remains benign.

The high El-CID signals in “Quad” mode are somewhat puzzling, considering the small temperature rise measured on Flux test. Therefore, it could only be concluded that the fault is small and not propagating rapidly. The Unit 7 stator will be both El-CID and Flux tested during the next maintenance outage.

One characteristic of this stator core that may be significant is the fact that it contains grain oriented coreplate. There is speculation that the high El-CID signal level obtained may not have the same significance on grain oriented coreplate as signals obtained on the more commonly used non-oriented laminates. Further investigation on this point is required. Ontario Hydro has begun some preliminary work in this area.

## **Conclusions**

The El-CID test is reliable in; detecting the existence of, and locating of core faults. Ontario Hydro has never had an occasion in over 80 tests done, where a Flux test has not verified the presence of core faults found by El-CID. Therefore, Flux tests are now only done when a fault is found by El-CID, and even then only when the nature of the fault is uncertain. Ontario Hydro takes the position that if no faults are found using the El-CID test, then there is a very high probability that the core under test is free of defects. This is the main benefit of the El-CID test in the view of Ontario Hydro.

El-CID has been used by Ontario Hydro on several occasions to reliably locate core faults or interlaminar insulation deterioration and to verify successful repairs. There have been more occasions however, where the El-CID test alone was not enough to characterize the fault under investigation. In these cases, a Flux test was required to finalize the; repair, need for repair, or monitor only decision. It is Ontario Hydro’s disposition that the Flux test remains the most secure method to characterize core faults and to verify the success of repairs.

More work is required in comparisons of EI-CID and Flux test fault data. With a larger database of faults investigated by both methods, there may come a point where the Flux test is obsolete and all core fault investigations and repair work can be governed by the EI-CID test alone.

There is some speculation that the core iron properties may also play a large part in the level of EI-CID signals obtained. The effect of this may be that the signal level cannot be used as directly read off the EI-CID signal processing unit. A 200 mA signal, for example, may be significant and indicative of a serious fault in one machine but not in another. It is further speculated that some calibration of the signals may be required based on the type of coreplate in the machine, and/or the specific electric and magnetic loading of the machine being tested. The grain direction may also play a significant role in the level of the EI-CID signal obtained in stators employing grain oriented coreplate. Further investigation of the possibility of such effects is warranted.