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EL CID

(ELECTROMAGNETIC – CORE IMPERFECTION DETECTOR)

TESTING OF LARGE STEAM-TURBINE-DRIVEN GENERATORS

Working Group A1.01.06

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EL CID (Electromagnetic – Core Imperfection Detector)
Testing of Large Steam-Turbine-Driven Generators

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1. Introduction

The EL CID technique was originally devised in the U.K. by the Central Electricity Research Laboratories and later developed by ADWEL International as portable test equipment for inspection and repair of rotating electric machine stator cores. It was devised as a low excitation power alternative to the high power level stator core flux test, to look for stator core inter-laminar insulation problems. Its application has been shown to be quite universal and applicable to turbine generators, hydraulic generators and small generators and large motors. The subject of this commentary however, is confined to the class of large 2 and 4 pole, round rotor machines, commonly referred to as Steam-Turbine-Driven Generators.

The information contained in this paper is a brief discussion of the EL CID test technique and a general description of the benefits, issues and limitations of EL CID testing. The focus here is on EL CID due to its commercial availability on the market, where-as a couple of other experienced low-flux test methods in use are only available through the various OEM's.

2. EL CID Background

Traditionally, stator core inter-laminar insulation testing has been done using the "Ring" or "Loop" flux test method, in which rated or near rated flux is induced in the stator core yoke. This in turn induces circulating currents from the faulted area usually to the back of the core at the core to key-bar interface. (Figure 1) These circulating currents cause excessive heating in areas where the stator iron is damaged. The heat produced is generally detected and quantified using established infra-red techniques. This method has been proven to be successful over the years but requires a large power source and considerable time, manpower and resources to complete.

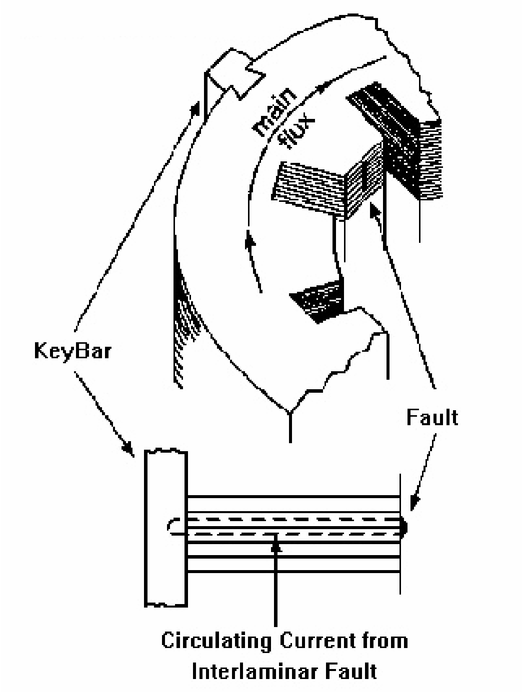

Figure 1 – Fault Current Path from Induced Test Flux

Within the past 20 years, the EL CID test has been developed as an alternative to the ring flux test. The technique is based on the detection of core faults by measuring the magnetic flux resulting from the current flowing in the fault area, at only three to four percent of rated flux in the core. Further, the test usually requires only two or even one man to complete (using the latest version) in less than one eight hour shift.

3. EL CID Test Procedure

The level of excitation to produce the desired flux in the stator core back area is generally determined by a combination of the stator design parameters and the power supply available to achieve the required flux level. For most generators, the standard 120 V AC (North America, etc.) or the 230 V AC (Europe, etc.) outlets with a current capacity of 15 to 20 amps is usually adequate.

The characteristics of most stators are such that 4 to 7 turns of a #10 AWG ($2.5mm^2$) insulated wire can be used to carry the excitation current for the test. The winding is then energized to the required volts per turns, to produce approximately 3 to 4 percent of rated flux, usually corresponding to around 5 volts per meter across the stator iron. A Powerstat or Variac is best used for voltage and supply current control.

The signal processing unit of the EL CID test equipment measures detected fault current (in QUAD mode) in mA. By theory and experimentation, as outlined in the EL CID manual by the manufacturer, a measurement of at least +/- 100 mA is required at 4% excitation of the core before it is considered that the core has significant damage affecting the inter-laminar insulation. (Details of the EL CID principles may be found in further reading of the EL CID manual by ADWEL and other references available from them.)

The excitation winding and power supply are set-up as shown in Figure 2a and 2b.

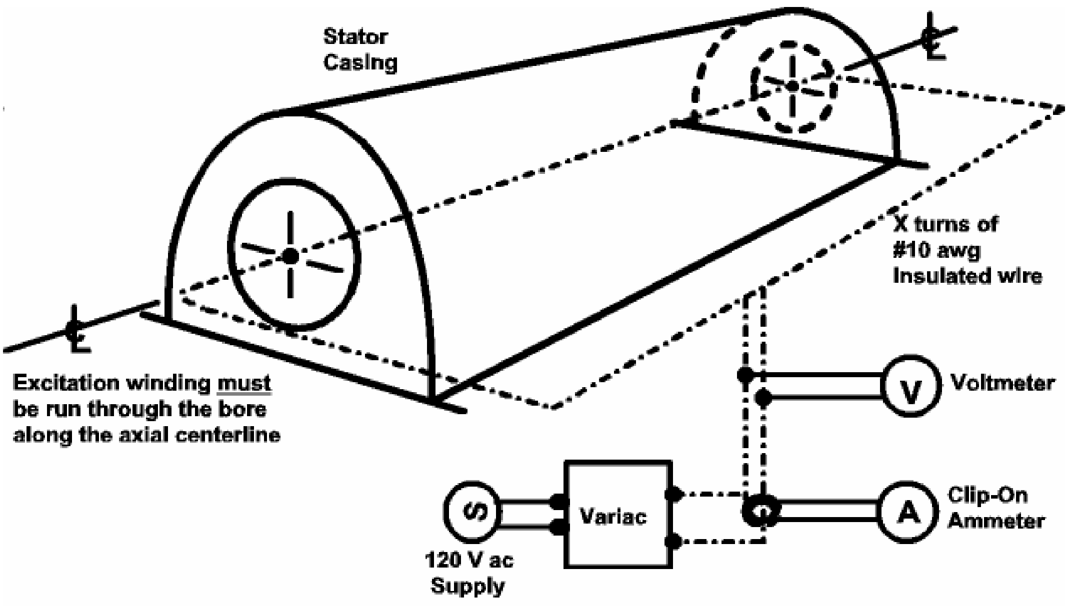

Figure 2a - Excitation Winding and Power Supply Setup

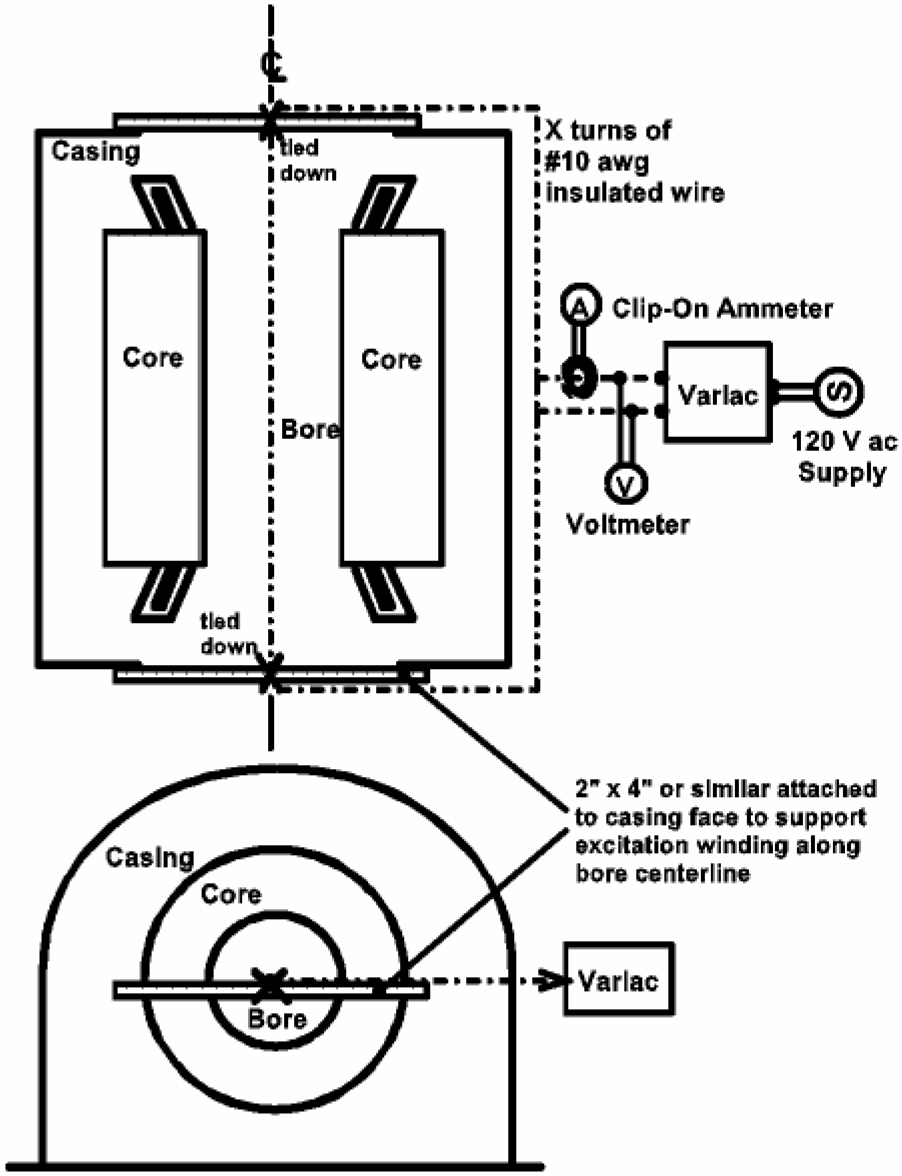

Figure 2b - Excitation Winding and Power Supply Setup

The EL CID equipment is set up as shown in Figure 3 (original analogue set) and Figure 4 (newer digital set).

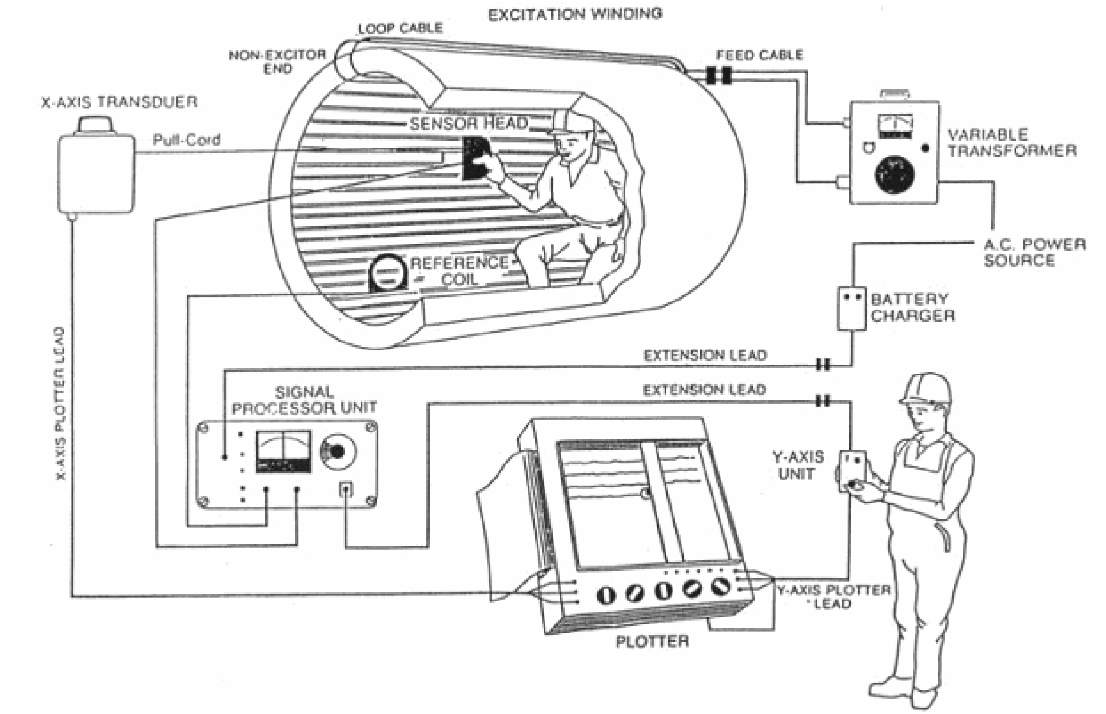

Figure 3 - Analogue EL CID Equipment Setup for
Testing Large Steam Turbine Driven Generators

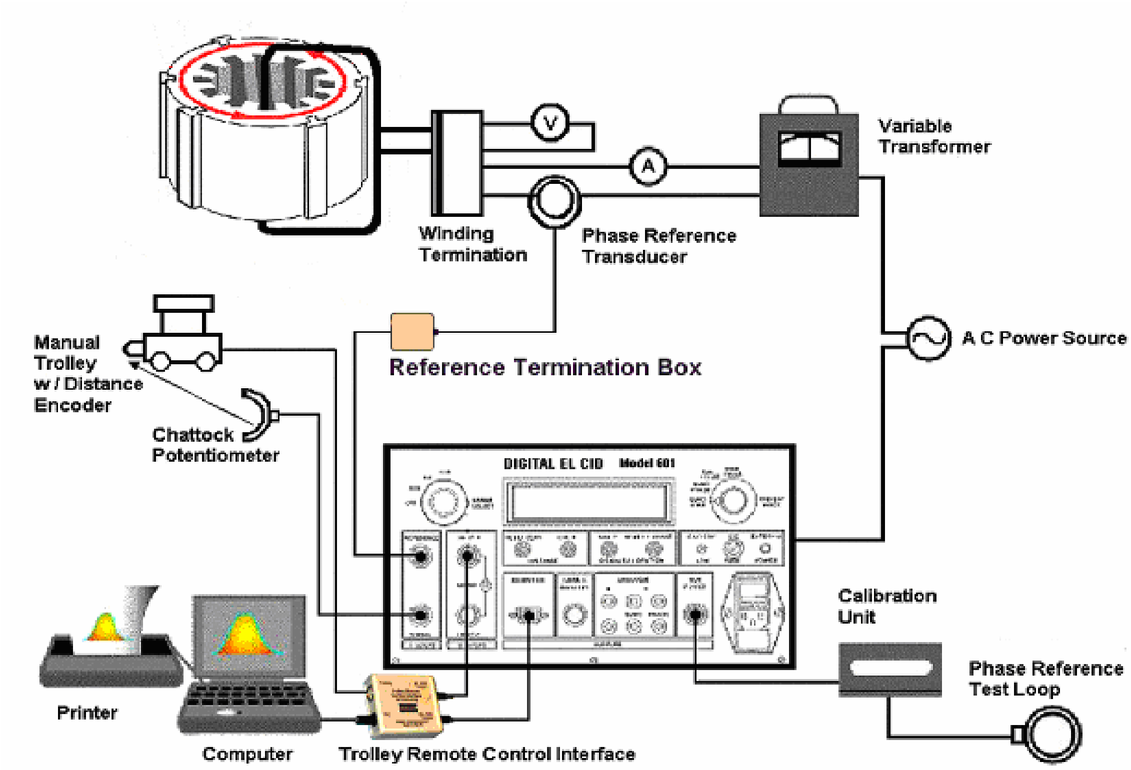

Figure 4 - Digital EL CID Equipment Setup for
Testing Large Steam Turbine Driven Generators

In the older analogue sets, a separate coil is placed in the bore over undamaged iron as shown in Figure 3, to supply the reference signal. In the newer digital version, a CT (shown in Figure 4) is placed around the excitation winding to reference the supply signal. The CT was also an option on later analogue sets. The digital equipment uses a laptop computer to store the axial traces, whereas a plotter was used in the original version.

The sensor head (Chattock potentiometer) is pulled axially along the core at a speed slower than one meter every twenty seconds and always bridging two stator teeth as shown in Figure 5. (The slower speed is important, as the standard Chattock has a magnetic sense area of only 4mm dia, and both the Digital and Analogue systems have a definite time needed to record the Phase/Quad signals to sufficient resolution. The Digital set records the Phase and Quad values every 2mm. Any faster testing results in some missed test points in the Digital system or potential inaccuracy due to settling time on the Analogue system).

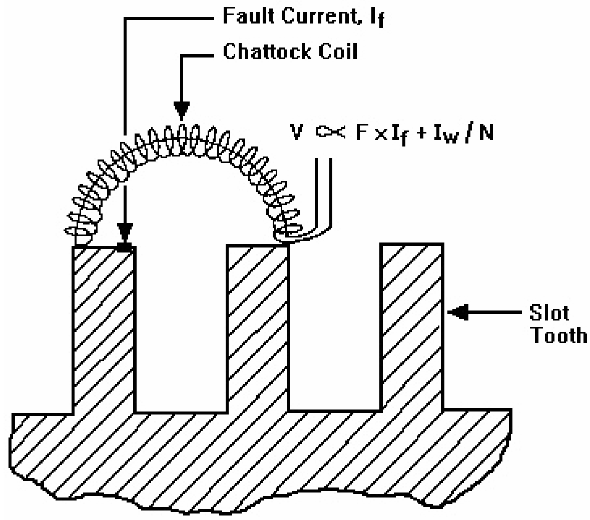

Figure 5 - EL CID Sensor Head (Chattock Potentiometer)

The fault current signal is read directly off the signal processor meter and input to a computer or chart recorder to trace out the readings as a function of the axial position along the stator core. When the sensor head is over undamaged iron, the meter should read zero if it is calibrated previous to the test for a condition where no fault current is circulating. In actual practice, no insulation system is perfect and some background signal is usually detected. In addition, the contact resistance of the core to key-bar interface is not zero and can be found to vary between near 0 to 2 ohms. This also affects the EL CID signal that is measured. Usually anywhere from a 0 to +/- 20 mA EL CID signal (in Quad mode) is found to be normal when good core is measured.

The above is somewhat similar to the rated flux test where the undamaged iron slowly heats up producing a background level due to eddy current losses in each lamination. During flux testing, this is recorded as the ambient core temperature rise. Where there is damaged or deteriorated core insulation, the core overheats and is detected as a hot spot above core ambient due to high fault currents circulating locally.

In the EL CID test, when the sensor head is placed over damaged core areas, the primary indication of a fault is obtained by detecting the flux produced by a current flowing in phase quadrature with respect to the excitation magnetising current (the PHASE current.). This flux is then converted back to an indicated current (the QUAD current) assumed to be flowing in the fault. For this reason the QUAD current detected by the EL CID processor is frequently referred to as the Fault current (although for large faults the PHASE current may be affected as well, especially where the Fault current path is highly inductive.). The QUAD current is indicated on the signal processor meter and the traces recorded on the plotter (original analogue EL CID equipment) or computer (newer digital EL CID equipment).

4. EL CID Experience

EL CID has proven to be extremely reliable in the detection and locating of core problems and can cut the time and manpower requirements for core testing to within one 8 hour shift, where a flux test may have taken a few days to set up and then a day to test and another day to dismantle the test equipment.

In the large majority of the EL CID tests on Turbo-Generator machines, the experience has been that EL CID is very reliable in determining that actual core faults or inter-laminar insulation deterioration exists. In other words, if a core defect exists, then EL CID is likely to find it. And if the core is indicated to be defect-free, by an EL CID test, there is a very high probability that it actually IS free of defects.

There are, however, a few questions in debate over the past several years on the ability of EL CID to determine the depth of any faults found, and the severity of any defects found, in terms of the actual temperature rise that would be produced during a flux test.

Firstly, there has been a significant amount of discussion on whether EL CID can actually see deep-seated faults. Generally the answer to this is, yes. However, most users of the equipment seem to be under the impression that the larger the signal read, the deeper the fault. This is not necessarily the case. In fact, large signals may be found at tooth top locations on the core and only indicate a significant surface fault. Local surface faults are generally indicated by faults which show very localized signals, either high or low in magnitude and positive in polarity if within the test coil span (assuming the standard EL CID test set-up). Deeper faults can generally be seen over a larger scanning area and also often become opposite in polarity as the sensor head gets away from the fault area. This is because the fault is outside the flux path of the Chattock coil sensing the fault current and the magnetic potential difference is reversed.

Figure 6 shows a general basic interpretation of the EL CID signals that can be expected to be seen based on fault location. The magnitudes in Figure 6 are only relative to one another, to give an idea of what might be expected for faults of roughly the same severity, at different locations. The peaks, and widths of the peaks, will vary from fault to fault as their size varies and as they are more or less severe. This then leads to the next point of signal magnitude and co-relation to temperature.

Attempts have been made to co-relate EL CID signal readings to temperatures that would be created in the defect area, during a flux test. The basic premise of the EL CID test significance level of +/-100 mA is that this level represents a 5 to 10 degrees C temperature rise that would be seen on flux test and therefore just at the level of temperature rise where most OEMs and experienced stator core experts would carry out repairs to the core iron.

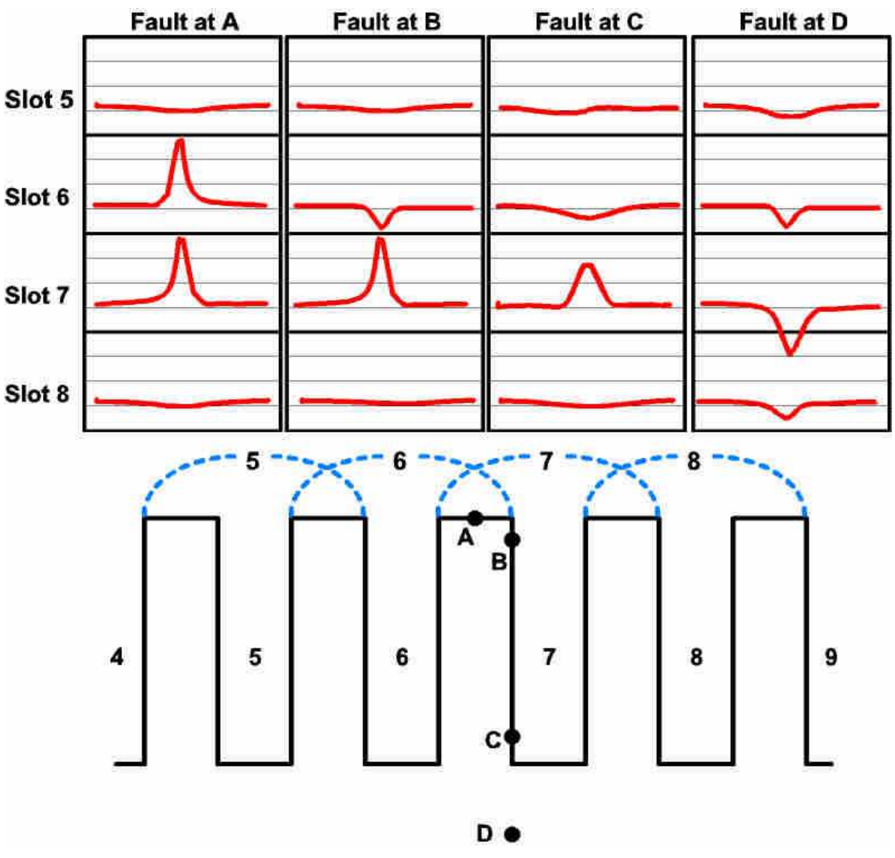

Figure 6 - EL CID Signal Interpretation

There are a number of issues with this premise that make this assumption of EL CID signal co-relation to temperature questionable. Firstly, many core testers carry out flux tests at widely differing flux levels. Some prefer to test at 100% of rated flux level while others test at about the 80% level. Different operators also apply the flux test over widely varying time periods. Yet, by all indications, all seem to work on the same temperature rise criteria. Obviously, a 10 degree C rise at 100% of rated flux is much less significant than at 80% of rated flux. This is because the 80% level is generally at the knee of the B-H curve and the curve is exponential. Increasing to 100% when the temperature rise is already 10 degrees C will increase the temperature in the fault.

There is also the influence and undetermined significance of core to key-bar contact resistance at the back of the core. The concern here is that the resistance can be generally measured to vary from near 0 to 2 ohms and may affect the EL CID signal as well as the temperature measured during a flux test.

For the low flux levels of the EL CID test, it may be quite significant. This is one of the unknowns for which there is little data to support this statement, one way or the other. But it should be noted that on un-grounded cores (i.e. cores with insulated key-bars and infinite core to key-bar contact resistance), the EL CID and the flux test are both ineffective unless there are two faults in proximity, to allow circulating current to flow and hence be detected by either test. This has been well proven by actual tests done on such cores, where single faults do not show up until the core is artificially grounded at the back near the key-bar that is behind the location of the fault.

Generally, there is only one key-bar that is grounded on such core arrangements (for purposes of the stator ground fault relay) and the testing is effective in that lamination region only, for single faults. To test such a core arrangement by either EL CID or flux test, the core must be purposely grounded at the back, between every key-bar, circumferentially and on every lamination axially. One can easily see the difficulty in this, as it is not even possible on most stator designs, because of the frame construction and arrangement. One has to consider this when purchasing a new stator. If a single core fault occurs, then the insulated core may allow operation where the grounded core would fail based on the progression of the fault. However, if a second fault occurs in the proximity, then this may lead to a failure of the core, if the two faults remain undetected. This is generally a matter of user preference and both philosophies are sound, each in their own way.

In addition, there is also the problem that core faults can manifest themselves in many forms and levels of severity. It is not uncommon for a surface iron smudge to show a very high EL CID signal and yet not produce much heat when looked at under infra-red in a flux test. And the opposite is also true. It is not uncommon for an EL CID signal which is not much higher than the manufacturer's recommended significance level, to produce significant heat. In particular, with very small faults on the surface where EL CID does not produce a significant signal, there are sometimes high spot temperatures detected by infra-red, but there is insufficient power to cause damage.

One advantage is that EL CID can detect deep-seated faults, which may often not show as a particularly large temp rise on the surface, but can be quite damaging to the body of the core or adjacent conductor bar insulation. This is due to the fact that the attenuation of EL CID signals is generally less than the attenuation of temperature rises with depth of fault.

The difficulty in co-relating EL CID and Flux test temperatures, therefore come from many issues as stated above and a number of other possible influences as listed below:

- Coreplate grade (i.e. grain oriented vs non-oriented steels)
- Lamination insulation grades
- Axial length of the fault
- Total size of the fault
- Electrical resistance of the inter-laminar fault (i.e. deteriorated or fretted insulation type damage with higher resistance as opposed to low-resistance, hard contact type faults)
- Geometry differences in core structure from one machine to another

- Limitations of the earlier EL CID test equipment, in relation to the size of the Chattock coil itself and the relative size of any fault being measured. (Current standard Chattock coils have only a 4mm diameter magnetic sense area, thus are able to detect very small faults, particularly if the suspected fault area is investigated/scanned slowly enough).

All these issues can have a significant effect on both the EL CID signal seen and the temperature produced during a flux test. Some are better known and quantified than others. Trying to co-relate temperatures to EL CID signals under so many variables is difficult unless all of these parameters can be taken into account. In other words, the core under test must be well known to be able to make such a co-relation.

There is one other factor regarding EL CID signal interpretation and that has to do with readings taken in the Phase mode, as opposed to the normal Quad mode reading that Figure 6 is based on. Basically when a stator has (for example) 4 turns of an excitation winding and is carrying 12 amps, then it has an excitation level of 48 Ampere-Turns. When the EL CID signal processor is set to Phase mode and a reading is taken from tooth centre to tooth centre across one slot, a signal of (48 A-T divided by 48 slots) 1 amp should be read. Generally, for most fault areas this is the reading that will be seen. However, in some cases, much higher current is read in the Phase mode than the simple magnetic potential based on excitation and slot geometry. One of the things that has been seen when this type of situation occurs, is that very high Quad readings are generally also present and the fault is usually at slot bottom or in the core yoke area. Correspondingly, there is not always much heat given off during flux testing and the two tests do not always correlate when this occurs. There is very little experimental data on this point and again it shows that some uncertainties remain in interpretation of EL CID test results. It is believed that Phase readings are also significant and should be factored into the test interpretation. Just what that interpretation should be is unclear to date, due to the difference in faults from case to case.

Probably the main difficulty for the test interpreter is, when nothing is known about the core under test nor the type of fault found. Most often, the core defect is not visible and what the tester is trying to determine is how deep it is and how severe it is. The general consensus of the people surveyed on this issue, is that more often than not, they cannot tell how severe a detected fault is and then require a flux test with infra-red scan to help in that determination. In that respect, the Ring Flux test remains the best test to determine the actual temperature rise of any fault and if repairs are required and if they are possible (though if the suspected fault is believed to be deep-seated from the EL CID test result, the Ring Flux thresholds should be appropriately adjusted). Once the core is repaired, an EL CID test can usually show that the repair is successful by the absence of a defect signal. This is perhaps the best value in EL CID testing.

There seems to be general consensus that if an EL CID test is performed and no damage is found, then the core is defect free. EL CID has gained good credibility in its ability to determine and locate the presence of faults and to verify repairs when faults are found. The general consensus also appears to be that more work is required on EL CID signal co-relation with temperature rise in fault locations.

The general feeling to date is that both the EL CID and Flux Testing together are still required to give the best information on any core defect found.

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