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Limited Access Inspection of Turbo Generators

Streszczenie. *Określenie „inspekcja generatorów z wirnikiem wewnątrz stojana"(z ang. LAI) odnosi się do pomiarów generatorów bez pełnego dostępu do wnętrza maszyny. LAI jest przeprowadzana w zastępstwie badań rutynowych, okresowych na turbogeneratorach jak i hydrogeneratorach bez konieczności wyjmowania pieńków wirnika. W ostatnich latach na skutek zmiany zażądania w przemyśle oraz dużych interwałów pomiędzy przeglądami głównymi turbogeneratorów nastąpił wzrost zapotrzebowania na usługę LAI. Najczęściej przeprowadzanymi badaniami są kontrola rdzenia stojana metodą EL CID, kontrola stanu zaklinowania stojana oraz inspekcja wizualna stojana i wirnika. LAI skraca czas postoju maszyny ze względu na brak konieczności demontażu wirnika jak to ma miejsce przy klasycznej inspekcji jak również zredukowane jest ryzyko wynikające z operacji wyjęcia wirnika.* ***Inspekcja generatorów z wirnikiem wewnątrz stojana***

Abstract*. Limited access inspection (LAI) is the term frequently used to describe inspection of rotating machines without full access to the stator core, i.e. with rotor not removed from the generator. LAI is used as substitute for routine and periodic rotor out inspections on both, hydro and turbo generators, with or without removal of salient rotor poles. In recent years, due to de-regulation of the industry and newer designs of high speed turbogenerators with very long major overhaul intervals, there was an increase in requirements for this type of testing. The most frequent tests performed are stator core interlaminar insulation testing (EL CID), stator wedge tightness inspection and visual inspection of stator and rotor. LAI has reduced extensive downtime due to rotor removal and assembly versus performing a conventional inspection and reduced risks associated with rotor removal and insertion.*

Słowa kluczowe: EL CID test, rdzeń generatora, inspekcja generatora, stan zaklinowania, inspekcja wizualna.
Keywords: Limited access inspections, EL CID test, stator core, wedge tightness test, visual inspection.

Introduction

An automatic scanning system was developed by the Central Electricity Generation Board (UK) in 1982 in which the Chattock potentiometer was moved along a beam clamped to the surface of the bore. This technique was devised as an alternative to the high power level stator core flux test, which needs a large power source. Automatic EL CID testing was later improved by a vehicle developed by National Power (previously part of the CEGB) which was magnetically attached to the stator surface and was steered itself along the stator teeth [2]. This vehicle was further developed by ADWEL in cooperation with the French Utility EDF and became commercially available in 1992. Further development reduced the size of the original vehicle and added visual and wedge tightness inspection modules, resulting in Robotic Inspection Vehicle Model 702, today produced by IRIS, Canada.

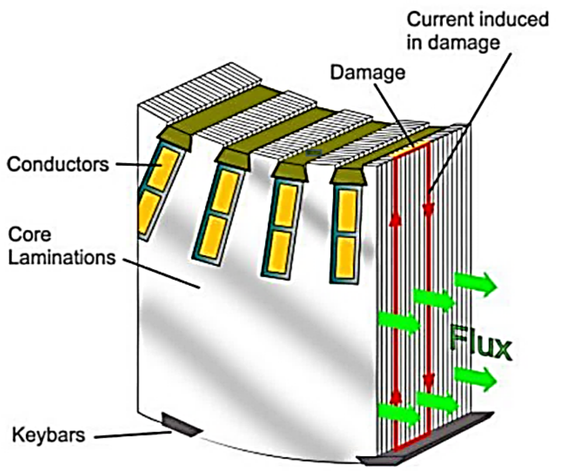

Fig. 1. Stator core with circulating current from interlaminar fault

Stator core faults detection

Stator magnetic core is a critical component in a generator, so the good condition is necessary for continuous and trouble-free operation. This requires appropriate and proven diagnostics method to determine actual condition [4,5,10]. Stator cores are made up of a great number of thin insulated iron sheets to reduce losses due to eddy current. During operation, thermal, mechanical and magnetic stress can deteriorate insulation between each sheet. Also during generator overhauls, the mechanical accidents may cause short-circuit on the core surface. If the lamination sheets are shorted together for one of the reasons above, then circulating currents producing higher I^2R losses at the point of contact may result in localized heating.

Circulating currents in combination with overheating can cause propagation of the fault. In final stage stator core can melt or due to high temperature main insulation of the stator winding can break down (Fig. 2).

Fig. 2 Melted stator step iron due to very high temperature (high value of circulating current)

Traditionally the stator core inter-laminar insulation testing has been done using Flux Ring Test (also known as a loop test). In this method, additionally excitation winding is energized to excite the yoke of stator core at 70-80% (at 100% for Full Flux Ring Test) of rated flux. To detect those areas where the inter-laminar insulation breakdown has occurred, infra-red cameras is used to find places with higher temperature. This technique is very useful to determine stator core condition and is reproducible to compare results from different inspections. Even today, after development of other less costly diagnostic methods, Flux Ring Test is one of the most reliable methods to determine real condition of stator core. However, Flux Ring Test have one very important disadvantage. To do this test a large power source is required to energized the excitation turns. For reason above, other technique to core lamination testing has been developed in the early '70 years. That technique is based on the detection of core faults by measuring the magnetic flux resulting from the current flowing in the fault area. During this test stator core is excited in around 4 to 10% of rated flux, which allow to use 230V, 30A power source. Today the most common low induction system is Iris Power EL CID - Electromagnetic Core Imperfection Detector. In EL CID diagnostic system the trolley with Chattock Sensor is moved along the stator core. Chattock Potentiometer measure the difference in magnetic scalar potential between its ends. Measured signal is result of the sum of two components of magnetic field in stator bore. First is the magnetic field due to the excited induction in the core and second is magnetic field arising from circulating currents in fault inter-laminar insulation area (if existing). These signals have the phase shift between each other of approximately 90° [6,8,10].

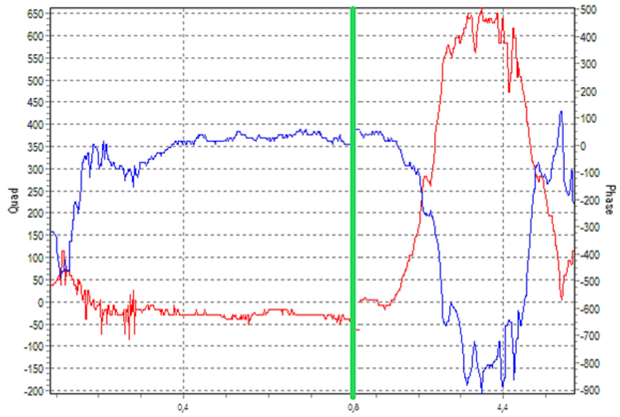

Fig. 3. Signal of Quad (red line) and Phase (blue line) in function of core length

Due to this phase shift, EL CID SPU (signal processor unit) can provide differentiation of current created by local fault from main magnetic field. That signal is proportional to the fault current in inter-laminar insulation short circuit. Final information from SPU, which informs about the occurrence of defects in stator core, is called Quad Current. In the original 1981 EL CID procedures, the safe value of quad current was 100 mA [10] and signal above 100 mA should be regarded as significant and investigated further. According to the EL CID manufacturer, the correlation between results of EL CID and High Flux Ring Test is: for each 100mA of Quad Current, temperature rise will be 5-10 °C.

Relations between quad current and temperature rise are not stable for every stator core and it is not possible to determine unambiguous dependence. For this reason many specialist of the EL CID inspection trying to determine appropriate criteria for relation between low and high flux test. One of the most recognizable of that specialists – G. K. Ridley, after analysed many results from EL CID and HFRT tests which has been done together, established EL CID criteria which allows better determine condition of the core and introduce the possibility of defining trend of stator core faults [9]:

Table 1. Indication of core condition base on Quad value

Quad Current Value	Indication of core condition
< 100 mA	Acceptable
100 to 200 mA	A possible problem, monitor periodically
200 to 300 mA	Monitor regularly for a potential problem
> 300 mA	Significant deterioration is likely

Wedge tightness test

Generator stator slot wedges fit into grooves near the tops of the stator core teeth (Fig. 4.) Loose wedges in stator slots can lead to vibration of the stator bars. The root cause of the problem is that at full load, the twice power frequency magnetic forces will vibrate the coils if the coils are not tightly held in the slot. Consequently, the groundwall insulation rubs against the laminated steel core – a very abrasive surface (Fig. 4). First the semiconductive layer of the bar or coil is abraded away, and then the groundwall insulation.

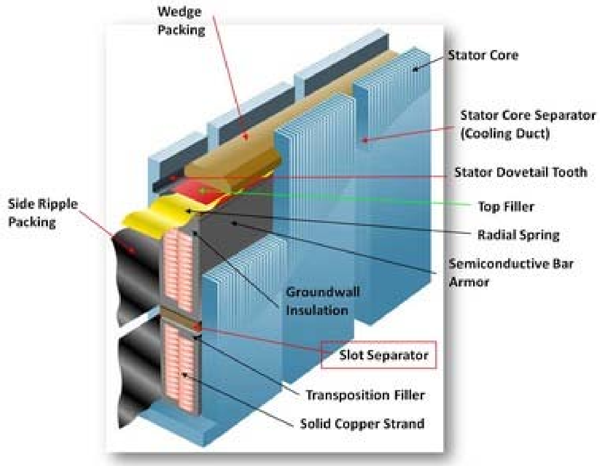

Fig. 4. Cross section of stator winding, slot part

The mechanism is sometimes referred to as slot discharge, because once the semiconductive coating is abraded, partial discharges occur between the coil surface and the core, further increasing the rate of deterioration (Fig.5)

Fig. 5. Damage of stator bar outer corona protection due to bar vibration.

It is very important that wedge tightness be carefully ascertained and corrected if deficient because the tightness of the stator wedge is the only structural element that prevents stator coil vibration due to the combined effects of magnetic and mechanical loading. Field experience has shown that failure to hold the stator coil stationary in the stator slot permits ever increasing levels of vibration leading to deterioration and finally failure of the stator mica insulation and, in many instances, grounding or "flashover" of the coils. When this occurs, the owner/operator of the unit is faced with a time-consuming and expensive rewinding process. For these reasons, stator wedge tightness is of interest during routine outages, and not just when the rotor is removed. The accepted industry method of testing stator wedge tightness is to "tap test" the wedge, feel the resulting vibration, and listen to the sound. A loose wedge will vibrate more than a tight one, and can be felt with the fingers. In addition, a loose wedge will emit a characteristic hollow sound, which the experienced expert can recognize as a loose wedge. Another method is computer method with use special dedicated equipment like wedge tightness detector. In this method an automatic hammer installed in a wedge tightness detector probe mechanically excites the wedge under test and the subsequent response values are processed to give a degree of tightness of the wedge. Main difference between those two test are that for manual method rotor need to be removed and experienced expert need to perform the test. Second method is based on use of calibration files and results are compared to required levels. Probe can be installed on the robot vehicle and test can be performed with rotor installed in the stator.

Robotic Inspection

The Robotic Inspection Vehicle (RIV) and accessories Fig. 6, allows remote and robotic testing to be achieved. The vehicle is attached magnetically to the stator teeth, and guides itself along each slot using magnetic sensors, to achieve and maintain correct alignment. The RIV is of particular value when there is only limited access in a small stator, or when a large amount of testing requires automation to reduce the labor involved (e.g. large hydrogenerators).

Fig. 6. Low profile Robotic Vehicle

The greatest gain however comes in allowing tests to be performed with the rotor still in place, where the RIV can be run inside the rotor-stator air-gap. Fig. 7 and 8 show RIV being launched into air-gaps in typical situations on two different turbo generators.

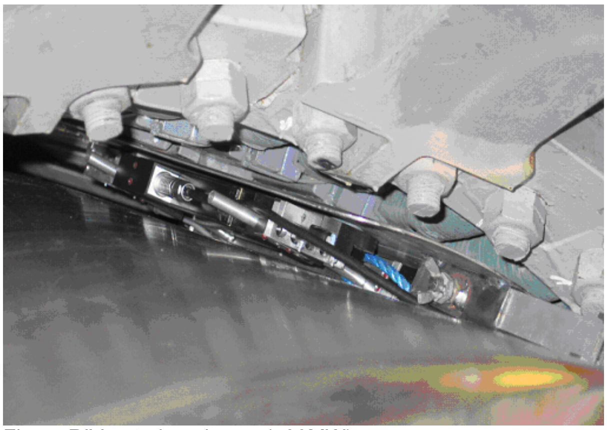

Fig. 7. RIV entering air-gap (500MW)

This test method is usually restricted to larger turbo-generators from about 100MW upwards, depending on access past the rotor end rings. In hydro-generators the air-gap is usually too small, but the gap between the poles can be exploited, possibly with a pole removed, then the rotor turned to allow testing of the whole core. There is no direct link between MW rating of the machine and size of the entrance/air gap, so larger the machine does not mean that the entrance gap is larger. However, it seems that older machines do provide larger entrance gaps, compared to newer machines of the similar rating.

Fig. 8. RIV entering air-gap (150MW)

Diagnostics possibilities of Limited Access Inspection EL CID test

Primary assumption for designers of Robotic Inspection Vehicle was delivery of low induction stator core tests. To perform this test, two Chattock sensors are mounted on both ends of the RIV to allow complete coverage of the whole core and distance encoder is used to record the distance (Fig. 9.). For full coverage of one slot two runs must be performed – one in forward, and the other in backward motion. For each run, separate signals from different Chattocks are recorded, so the final result for one slot is two traces of Quad current in function of travelled distance.

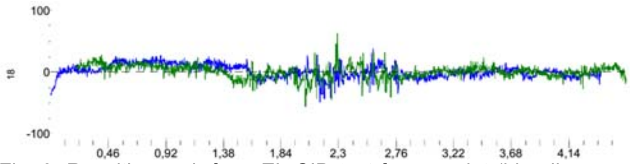

Fig. 9. Result's graph from EL CID test for one slot (blue line - run forward - used rear Chattock sensor, green line - run backward - used front Chattock sensor)

In rotor-in-place testing the excitation cables cannot be taken down the center of the bore, but must instead be threaded through the air-gap between the stator and rotor. It may be expected that this will lead to rather asymmetric excitation of the core, however F.E.A. analysis of a typical 48 slot turbo-generator has shown that the effect of the iron in the rotor is to linearise the magnetic field at its surface, so the flux remains uniform in the main core. The only precaution that needs to be taken is the usual one of making sure that the Chattock does not approach too close to the excitation cable to avoid interference from the winding leakage field.

Fig. 10. Sample of visual inspection during LAI – movements in rotor wedges

Fig. 11. Cracks of paint on rotor wedge - probably loose wedge

Visual inspection

One of the additional devices which can be mounted on RIV is high resolution video camera which allow to perform visual inspection during runs. Camera is mounted in front of the RIV, and can be rotated in two planes. This allows to observe stator core surface, stator and rotor slot wedges, rotor surface and stator and rotor air ducts.

Wedges tightness test

The ability to introduce the RIV into the air-gap with the rotor still in place also allows measurement of wedge tightness. The RIV can carry a low-profile SWA Wedge Tightness Probe (previously WDT-501), allowing a survey of the wedging system without rotor removal. Test results are given in the same way as when the test is done by hand-held probe and there are showed as color wedge tightness map.

S\W	1		2		3		4		5		6		7	
1	54	52	84	83	100	100	75	100	100	100	100	100	75	74
2	58	56	83	100	100	91	100	77	92	82	100	100	100	100
3	98	92	59	100	100	78	99	69	100	100	76	100	97	98
4	48	50	84	100	100	100	100	100	100	100	100	100	100	100
5	61	61	55	89	73	67	100	100	83	100	100	100	57	55
6	81	86	100	100	100	100	100	100	100	100	100	100	97	98
7	57	58	100	100	100	100	100	100	100	100	100	100	100	100

Fig. 12 Wedge tightness test map

Fig. 13. Low-profile SWA Probe

Utilization of equipment for visual inspection and checking wedge tightness condition greatly increased the possibilities of Limited Access Inspection. Based on full information from LAI it is possible to decide about necessity to remove rotor to perform the necessary repairs in future.

Advantages, Disadvantages and Risk of LAI

LAI of large turbogenerators is an attractive alternative to inspection requiring rotor removal due to great savings in time required to perform the task. There is no doubt that LAI will save maintenance costs versus rotor out inspections. The amount of savings is dependent upon the individual plants situation and will be affected by factors as such as:

- Amount of disassembly required
- Closed vessel rules (i.e. confined space restrictions)
- Amount of station support required
- Length of inspection
- Reassembly material required
- Crane requirements
- Rotor storage/protection
- Rotor alignment
- Risk of damage to rotor, stator and other components during the rotor removal and insertion
- Risk of oil leak introduction
- Foreign object material damage potential avoidance

Depending on the above factors, time required for robotic inspection could be anywhere from 3-5 times shorter than time required for traditional inspection, resulting in savings that are measured in hundreds of thousands of euros.

Disadvantages of LAI are related to possibility that rotor removal might be required after the limited access inspections, either to perform the repairs or to verify the critically important findings. Although there are no such reports, there is also a risk of robotic vehicle failure that is usually controlled by evacuation methods. Obvious disadvantage of LAI is lack of human touch and feel, which is an important part of rotating machine inspection. Entrance gap in some newer machines may prevent use of the most vehicles available. Also, some of the stator designs incorporating baffles cannot be tested with vehicles that travel in axial direction only.

LAI experiences

Case Study 1

Visual evidence of possible core damage was photographed and the inspection vehicle was used to move the Chattock sensing coil of the Iris Power EL CID along stator core to test the damaged area. The information obtained indicated that the damage was not sufficient to warrant removing the rotor.[3]

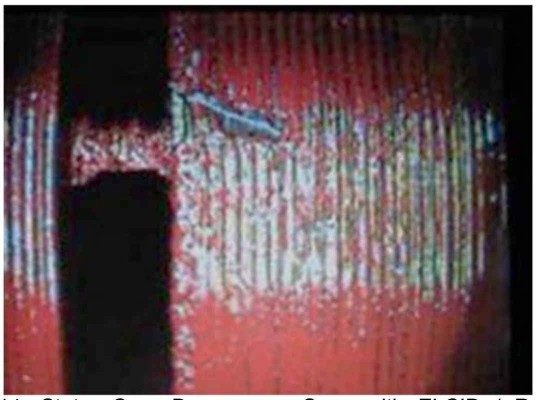

Fig. 14. Stator Core Damage as Seen with ELCID / Robotic Inspection Vehicle Camera

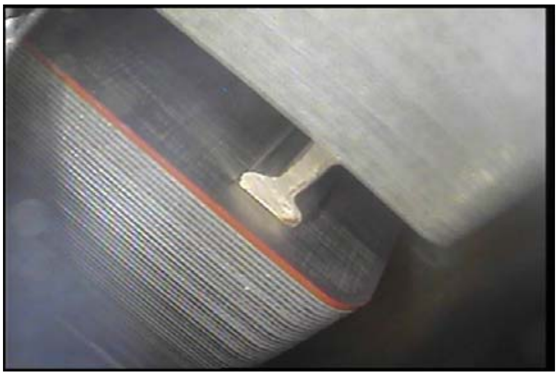

Fig. 15. Clean surface of air duct in middle part of the core

Case Study 2

During Limited Access Inspection which was done on 3 years old generator, rust has been found inside air ducts in the end region of the core. Based on this information It was decided to continuous use of anti-condensation heaters to eliminate moisture while generator is not operating.

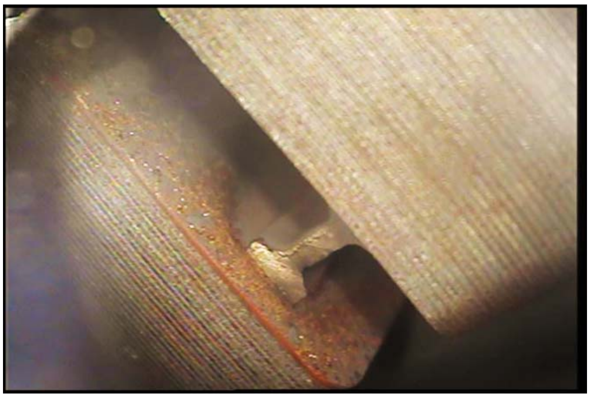

Fig. 16. Rust on air ducts surface in end region of the core

Case study 3

In some type of generators, LAI can be done without major disassembly of generator end covers, seals etc. To place the robot inside the air gap, it might be possible to use inspection holes after removal of covers and/or rotor fan blades inside generator frame. Possibility to perform LAI on full closed generators are usually restricted to older generators with rated power over 300 MW.

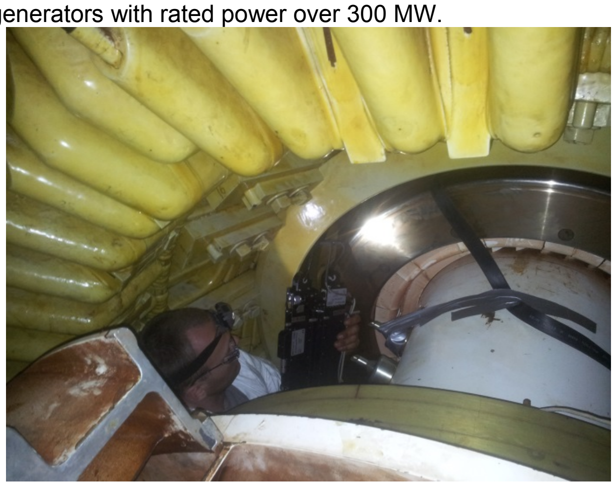

Fig. 17. LAI on full closed generator BBC 425 MW.

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REFERENCES:

[1] Experience with Limited Access Generator Inspections, *EPRI Report 1000100 September 2000*
[2] D. Bertneshaw, J. Sutton, M. Sasic; 30 years of EL CID use; *IRMC conference 2007*
[3] Mc. Dermid, Repair of a Damaged 300 MVA Machine, *IEEE ISEI June 2010*
[4] W. Kandora, M. Rad, W. Rams, Wykrywanie defektów rdzeni maszyn prądu przemiennego metodą skanowania magnetycznego, *Maszyny Elektryczne - Zeszyty Problemowe nr 1(98)/2013*
[5] W. Kandora, Skanowanie magnetyczne rdzeni stojanów turbogeneratorów - *XIV Międzynarodowa Konferencja Naukowo-Techniczna Forum Energetyków GRE 2014*
[6] C. Rickson, Electrical machine core imperfection detection, *C Eng. M.I.E.R.E.*
[7] C. D. Rickson, A New Technique for core lamination testing
[8] G. K. Ridley, EL CID – Application and Analysis
[9] G.K. Ridley, Hydrogenerator EL CID results referred to High Flux test results
[10] J. Sutton, Procedures for the use of electromagnetic core imperfection detector (EL CID), *CEGB ED/L/R 1981*