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REPAIRING GENERATOR STATOR CORE SURFACE DAMAGE BY ELECTRO-ETCHING – A CASE STUDY

1 ABSTRACT

In this paper a real-life case of repair of minor generator stator core surface damage by electro-etching method is presented.

2 INTRODUCTION

2.1 Generator

The generator is 120 MVA 3000 rpm 10,5 kV turbo generator. It suffered a catastrophic stator winding failure on winding end area. The resulting light arc, fire and contamination damaged the stator winding beyond reasonable repair, however the stator core stayed undamaged.

The stator was repaired by full rewinding.

2.2 Cause of the core damage

The old damaged winding was removed. Because the winding was made with resin rich technology the bars were not glued in the stator core slots like in global VPI process. Therefore after cutting the winding ends it was possible to remove the bars relatively easily.

In original manufacturing the fit of the bars in the stator core slots was made tight by round packing (dry graphite tape wrapped around the bars), any ripple spring materials were not used.

Some bars were stuck, likely because they were bent in the middle which expanded the bar width in the bending point. They were then forced out using a kind of large crow bar, which was supported against the bottom of the slot. The bottom of the slot was protected with a hard glass fiber laminate and the crow bar did not have any direct contact on the bottom of the slot.

However the pressure applied on the bottom of the slot was able to create metallic contacts between individual laminations. They were not exactly on the same level, and the pressure was able to spread the steel of the slightly protruding laminations in such way that it created a direct metallic contact with neighbor laminations.

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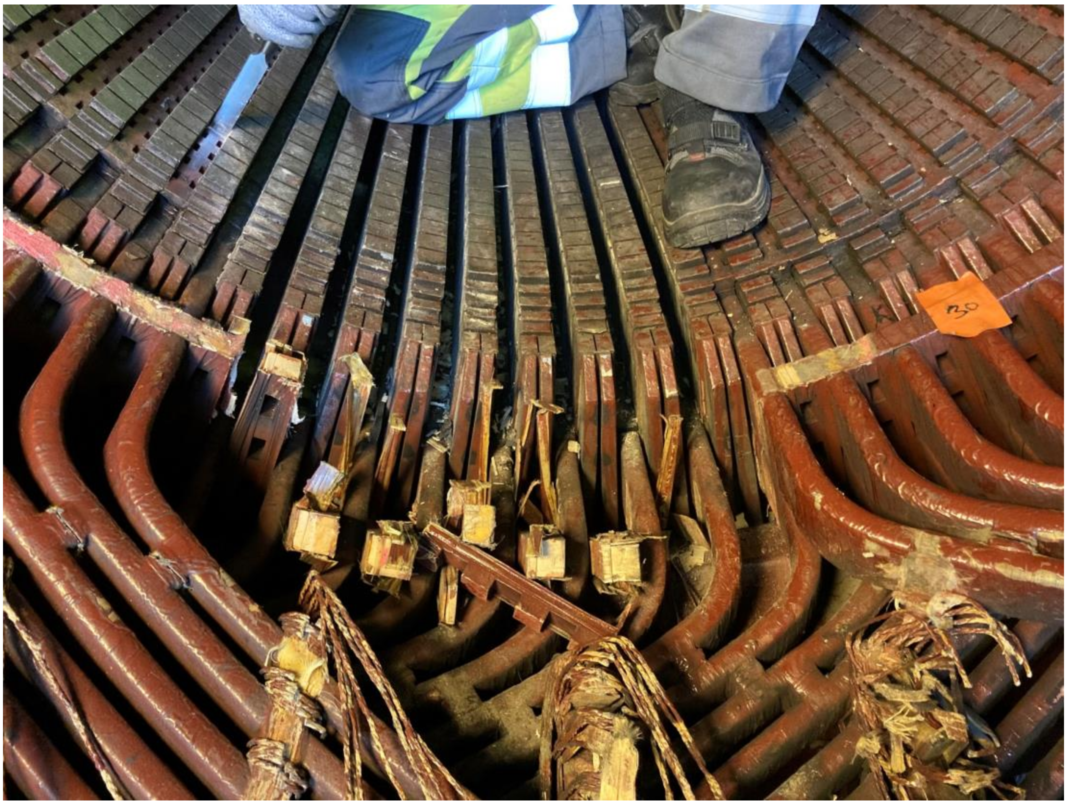
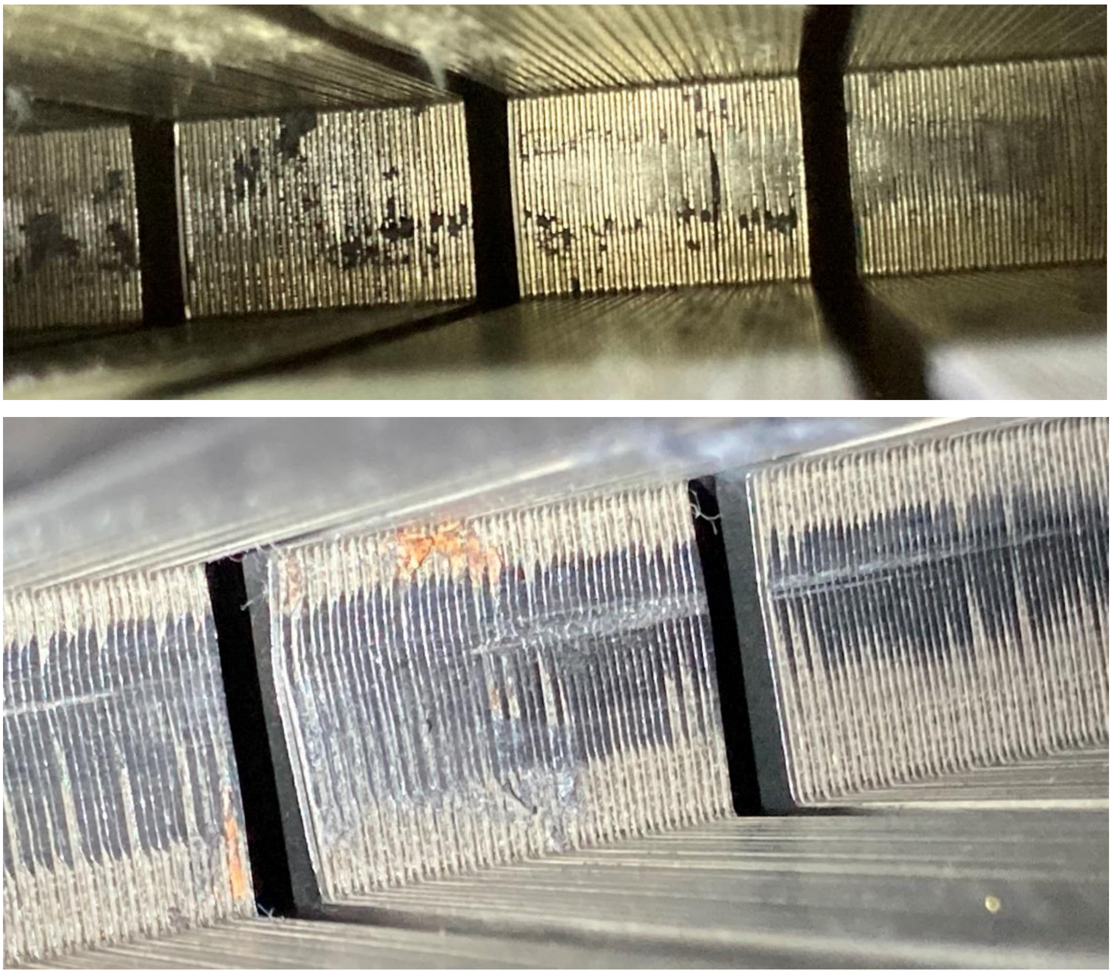


Picture 1. Damaged stator winding being removed for rewinding.

Picture 2. Round packing type of fitting on the removed stator winding bars.

2.3 Detection of the damage

It was easy to see the surface damage in visual inspection. The length of the damaged area in one stator core slot was some 40 cm, in addition there were some short 2 – 3 cm damaged areas on some slot ends.



Picture 3. The damage on stator core slot bottom. Metallic contacts between individual laminations are obvious.

An ELCID measurement was also performed on the core.

Abbreviation ELCID stands for Electrical Core Imperfection Detection, and the method is based on detecting interlaminar short circuit currents with a probe system, when the core is excited with low (2 -10 % of rated) flux. It is not based in infrared imaging like ring flux test at high flux. The measurement equipment is a commercial product of Qualitrol Iris Power.

The damage on slot bottom was clearly detectable in the ELCID results. Measured I_{quad} = 130 mA at 4 % excitation indicates a possible local hot spot 5 – 10 °C above healthy core areas at normal operation.

Picture 4. ELCID I_{quad} curves of the damaged stator core slot (in the middle) and two neighbor slots. Deviation I_{quad} = 130 mA indicates a possible local hot spot 5 – 10 °C in normal operation.

3 ELECTRO-ETCHING REPAIR METHOD

3.1 Introduction

The method is not developed by the author or his employer company. It is a well-established method described in text books, e.g. in reference [1], pages 453 – 454 in second edition 2008.

The purpose of electro-etching is to remove a thin layer of steel from damaged core surface without removing the thin insulation between individual laminations. This is possible with electrolysis reaction, where some acid-water solution is used as an electrolyte and a DC voltage / current source for maintaining the reaction.

The electrolyte recommended by [1] is water solution of phosphoric acid. Liquid phosphoric acid (e.g. 75 % solution) is available on hard ware stores, where it is sold as rust removal agent. It can remove rust from steel without electrolysis, however it is not able to significantly corrode the steel itself without electrolysis.

3.2 Test etching

Some tests were arranged before working on the stator core.

Picture 5 shows a test piece of structural steel where the electrolyte solution 30 % was applied absorbed on a cellulose pad, which was hold in place with stainless steel electrode connected to the minus pole of the DC source. The cellulose pad was replaced whenever it became dry. The plus pole of the DC source was connected directly on the steel.

Picture 5. Test etching on a piece of structural steel. The area 30 mm x 18 mm in the middle was etched appr. 4 h with low 2 A DC current, which removed some 0,2 – 0,3 mm of the steel surface.

3.3 Practical implementation

As instructed by reference [1] water solution of phosphoric acid was used as an electrolyte, here 25 % solution was used.

It was absorbed in a cellulose pad, which was actually piece of cleaning cloth. The suitable material was found in tests by trial and error; some cleaning cloths contained plastic and melted. Reference 1 recommends use of glass wool. The temperature will not rise very high, therefore also cellulose works.

The non-corroding cathode was stainless steel.

The corroding anode is the stator core.

A simple tool was made to handle to stainless steel cathode against the bottom of the slot, as shown in pictures 6.

The DC source was an inexpensive (in the range of 250 USD) laboratory source. It is important that it is adjustable to find the correct settings.

When the electrolyte pad is becoming dry the current will decrease. This can be temporarily compensated by increasing the voltage, but eventually the pad has to be replaced with a new one with fresh electrolyte.

The liquid electrolyte bubbles when the process is on-going and releases small amount of hydrogen H_2. The removed iron turns into iron phosphate and is absorbed by the pad.

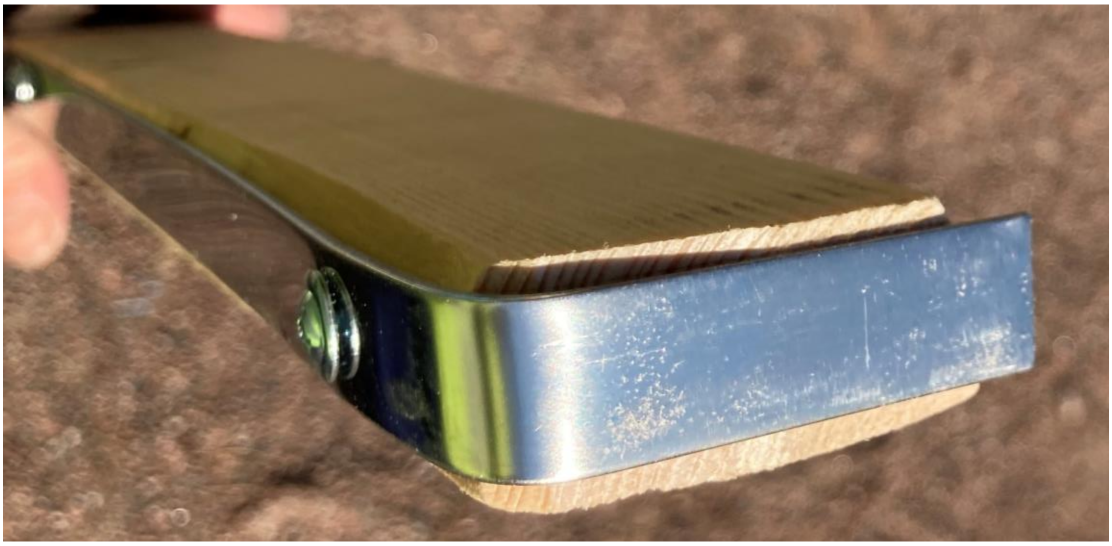
The speed of the process can be controlled with the DC source. Using higher current accelerates the process, however too high current will start boiling the electrolyte, which is unwanted. When the current is cut the electrolysis stops immediately.

The needed current depends also on the surface area etched at one time. Here less than 10 A and 10 V DC was needed.

The etching was performed in one small area at a time, and it was stopped when visual inspection showed that the individual laminations can be seen again, as shown in picture 10.

The repair described in this paper was completed in one normal working day.

The etched areas on the slot bottom were wiped clean and dry and then varnished to prevent rusting. It is important not to varnish any other areas to maintain good electrical contact of the bar slot corona protection electrode to the slot steel wall.



Picture 6. Wooden tool made to bring the stainless steel electrode with the electrolyte pad on the bottom of the slot. This is connected to the minus pole of the DC source. The stainless steel electrode is not corroded in the process.

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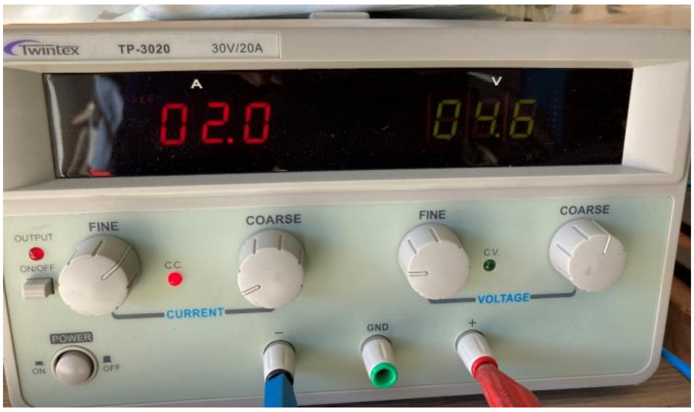
Picture 7. Pad wetted with electrolyte is held in place against steel core (here tooth top corner) with the tool holding the stainless steel electrode connected to DC minus. The stainless steel must not touch the core directly, because that will short circuit the DC supply. The area underneath is protected by covering it with cardboard.

Picture 8. The core is connected to the DC plus.



Picture 9. A standard inexpensive laboratory DC source was used for the electrolysis.

3.4 Safety considerations

Phosphoric acid is not poisonous, it is actually used in the food industry e.g. in beverages like Coca Cola.

However it is acid and can irritate skin and cause serious damage to eyes. In the etching process some vapor can be released, which must not be breathed in.

Therefore a recommended minimum set of safety equipment consists of fully covering clothing, rubber gloves, full face mask and a respirator or effective local ventilation.

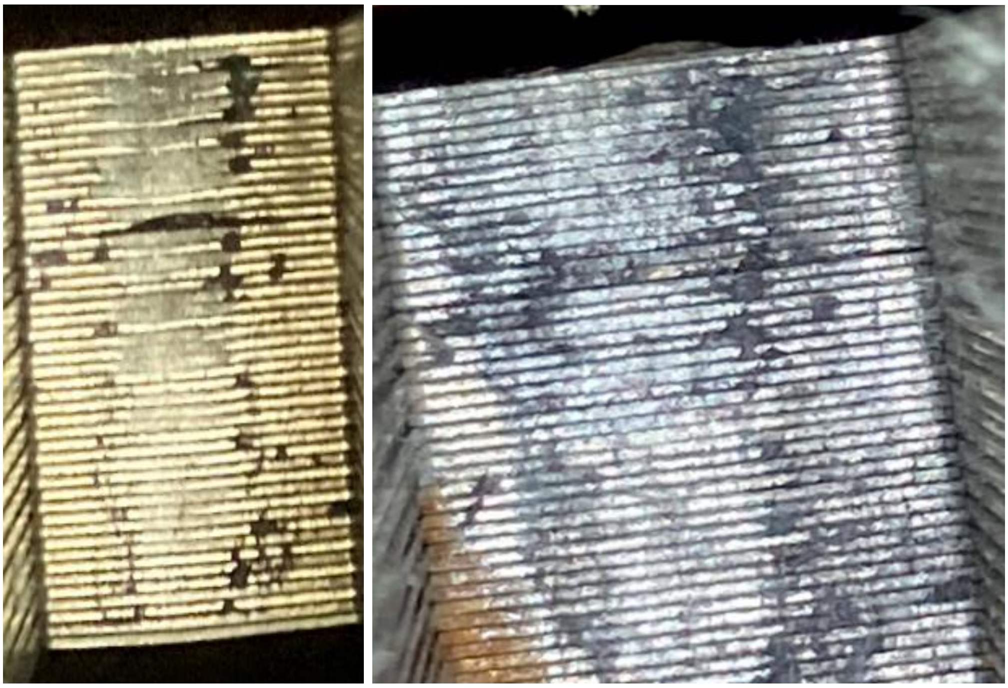
The used voltages and currents are low and not dangerous as such, however bringing a mains supplied DC source inside a grounded stator core poses a risk of electrical shock. It is recommended to supply the DC source through an isolation transformer which is located outside the stator core and to place also the DC source outside the core, if possible.

It is highly recommended to reserve an emergency eye flush bottle at the work site and not to perform the work alone.

4 RESULTS

4.1 Visual confirmation

Picture 10 shows the situation before and after etching in one location.



Picture 10. Before etching (left) the spread steel is connecting laminations. After successful etching (right) the spread steel has been removed and the insulation between individual laminations is visible again. It is exactly the same spot in both pictures.

4.2 ELCID measurement

ELCID measurement was repeated after the etching. The results confirm that the work was successful and the core fault indication has disappeared.

Picture 11. ELCID measurement confirms the core fault indication I_{quad} = 130 mA has disappeared.

5 CONCLUSIONS

Electro-etching method is an effective and safe method to repair shallow surface damages in stator core, if the area is accessible. As suggested in reference [1] deeper surface damages can be first machined mechanically and then treated by electro-etching to remove burrs and spread metal connecting laminations together.

The method is not suitable for handling core faults that are deep inside the core steel.

6 REFERENCES

[1] Handbook of Large Turbo-Generator Operation and Maintenance
G. Klempner and I. Kerzenbaum, Second Edition 2008
ISBN 978-0470-16767-0