Stator core condition assessment with CPC 100

The Stator cores of rotating machines are composed of multiple stacked layers to minimize eddy current losses. A short between two or more layers lead to higher local eddy currents. This again can lead to local hot spots which in a worst-case scenario, can cause a partial core melt and eventually the complete damage of the machine. A ring flux measurement, where the machine is excited at rated flux and the detection of the potential hot spots is performed with a thermographic camera, demands a high amount of power. Furthermore, the setup is both time- and resource-consuming.

The stray flux measurement with the CPC 100 is a reliable alternative, using a portable power source and measurement device that can be energized via an ordinary power plug. Beside the measurement at rated frequency, the CPC 100 allows you to excite the stator core at higher frequencies up to 400 Hz. The effect of the injection at different frequencies, detection of faults "deeper" in the core as well as the comparison to a ring flux measurement is explained in this paper.

I.   INTRODUCTION

To detect weak spots in the insulation of stator core segments, among other methods a stray flux measurement is used. In this case, a small percentage of the rated flux in the range of 2-10% is induced into the core via an auxiliary winding (Figure 1 left side) [1]. If a short between the lamination occurs, a higher eddy current – driven by the induced voltage from the auxiliary windings flux – causes a higher stray flux as shown in Figure 1 on the right side.
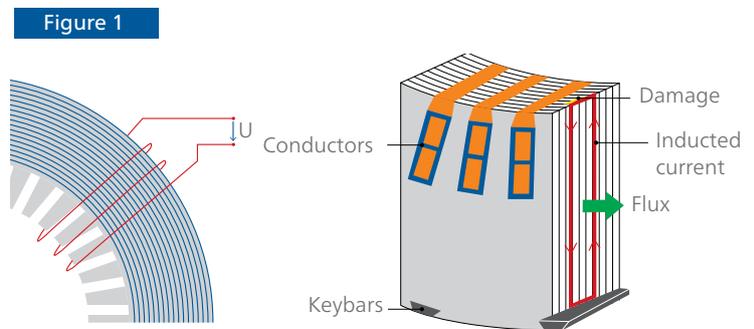
Figure 1

Left side: Auxiliary winding with indication of blue flux lines; Right side: higher eddy current due to a damage in the stator core.

This is detected as a higher stray flux by a Chattock for Rogowski coil scanning the stator surface as explained in Figure 2. [3] The readings of the coil are in mA correlated to a certain position within the stator core. As the measurement coil width and the number of turns of the sensor remains the same for each measurement, a calibration can be obtained prior to each measurement.

When measuring at an injection at 4% of rated flux [1], the excitation of the source does not need to deliver typically more than 2-3 kVA [2]. Even lower power is needed in most machines. This represents the major advantage compared with other methods, such as the high flux measurement, as the power supply and the setup for this test are fast and easy.

A common value at which locations should be investigated is 100 mA of the quadrature current, when measurements are performed at 4% of rated flux and rated frequency [1, 2].

Figure 2

Chattock coil
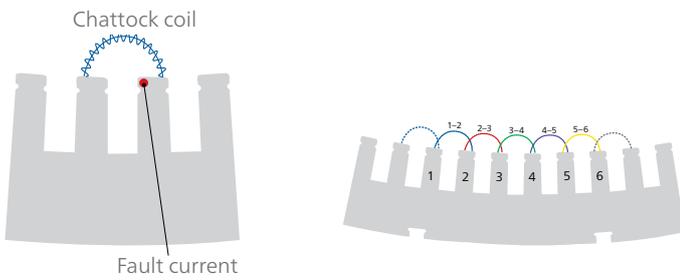
Fault current

Detection of the fault current by measurement of the stray flux by the sensor. Different slots are sequentially scanned by different measurements. The coil span is between the teeth of one slot to the next slot to ensure a certain overlapping area.

II. PARTICULARITIES OF THE SOLUTION

The explained parameters in Chapter I are valid for the CPC 100 solution as well. Additionally, some other particularities of this solution enable a fast and reliable measurement, including an intuitive operation:

A. Usability improvement due to semi-automatic sensor movement

Knowing that a manual measurement can be cumbersome and time-consuming, the intention was to increase the usability as much as possible. Therefore, a semi-automatic movement of the sensor comes with the stray flux measurement solution. The rail (RAA1) enables this movement and is placed with strong magnets onto the stator core. Additional fall arresters ensure that the rail cannot fall once positioned and damage any devices.

The sensor on the slide travels over the stator surface at a distance of between 2-3 mm, which ensures a sensitive measurement. Furthermore, no spikes are present in the results from the ventilation ducts or other unevenness if the coil support is not touching the surface.

Figure 3
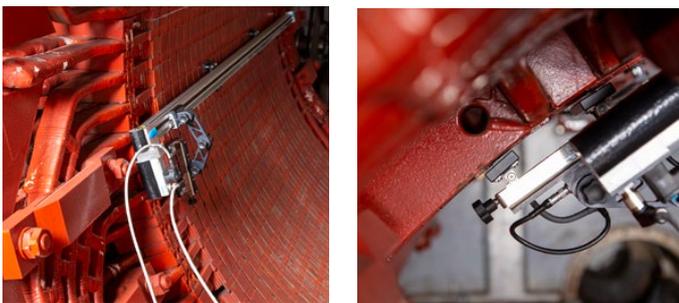
Rail and coil support during a measurement

The maximum length the rail can cover is 1760 mm. Longer stators can be measured as well, as the results of the different measurement methods can be combined in the software. The recommended approach in this case is to divide the stator in segments and measure each segment, as explained in Figure 4.

For local diagnosis as well as for special cases, such as long stepped end areas of large turbo generators, for example, measurements in a manual mode are also possible.

Figure 4

2nd measurement

3rd measurement
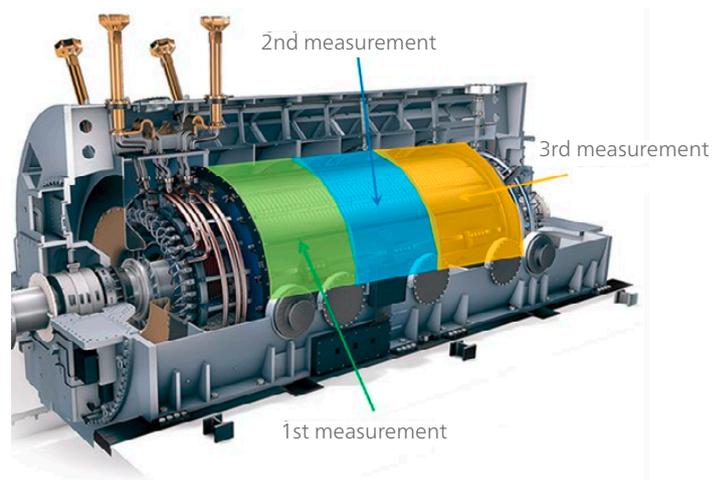
1st measurement

Measurement approach if long stators need to be scanned; Picture-Source Generator: Siemens

B. Excitation and measurement as a turnkey solution

The required power of less than 3 kVA enables the CPC 100 to act as a source and measurement device in one solution. Even higher excitation power, also from the output of an ordinary power plug, is possible, as the excitation is only active when the rail is moving, Together with the rail (RAA1), the control unit (SCU1) and the winding multiplier (WMP1), users have all they need to perform the measurement.

The excitation cable is already included and can be extended, if larger machines are measured. Two different excitation cables can be connected, such as a two-wire and an eight-wire cable, depending on the type of machine to be measured.

Figure 5

Excitation loop

Field Sensor
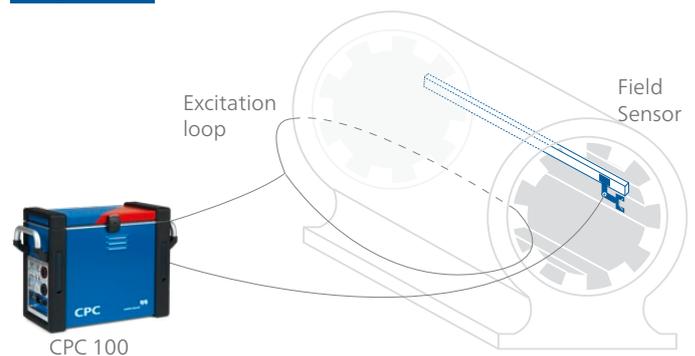
CPC 100

Simplified schematic of the CPC 100 as both an excitation and a measurement device

C. Primary Test manager support

Guidance throughout the test, including connection schemes and an automated calculation of the excitation winding depending on the winding scheme (if available) or otherwise on the stator dimension are provided by the operating Primary Test Manager (PTM) software.

Intuitive real-time signal display and a summary of the measurement by help of a heat map as shown in Figure 14

are also part of the software, as well as a one button report function. The report function includes all the other tests on the asset that are possible as well using the CPC 100.

III. EXPERIMENTAL SETUP

The investigations regarding reproducibility and measurement with different frequencies have been performed on a small decommissioned hydro generator with a rated voltage of 6,4 kV and 156 slots. The stator winding is a coil winding with 2 turns per coil. All other experiments described in Chapter VI and Chapter VII have been performed on different machines. The setup is explained in the corresponding chapters.

The investigations regarding the reproducibility of the measurement results as well for a better visibility of the effect of different excitation frequencies, the experiments on the small hydro generator have been carried out with a measurement over an artificial fault. A stator segment is shorted by a wire as explained in Figure 6. The reason for this modification is that it is an easier modification with the wire over two ventilation ducts rather than damaging the stator core.

In Chapter IV, a different artificial fault was used than in Chapter V.

Figure 6
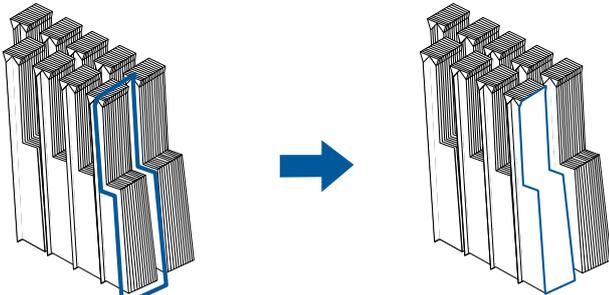
Explanation of the implementation of an artificial fault. A wire is wrapped around a core segment and shorted afterwards (left). Electrically this can be seen equal to a core segment without laminations (right).

IV. REPRODUCIBILITY

In order to be sure that the often-used interpretation limit is not influenced by the measurement setup, investigations on the reproducibility have been performed. This becomes even more important, as the user wants to have a trending over time, to estimate the criticality of existing potential weak spots. The first comparison in Figure 7 shows two measurements on the same slot with a fault in it, without changing any setting.

Figure 7
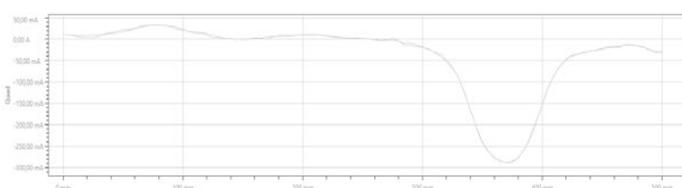
Two measurements of the same slot

As the high reproducibility is not surprising, in the next comparison in Figure 8 the mechanical setup and adjustment were performed each time at the beginning of each measurement. In this case, the same "healthy" slot was scanned, so no fault was implemented in these measurements. Each measurement trace was recorded after re-doing the mechanical setup each time at the beginning of each measurement. The spread of the results is higher than in Figure 7, but still very low and does not present a hindrance for reliable measurement.

Figure 8
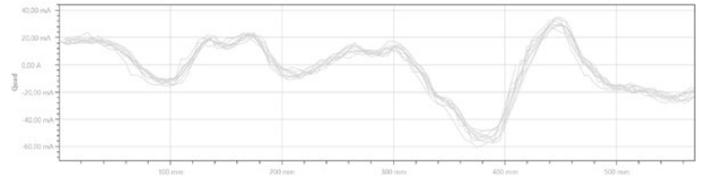
Explanation of the implementation of an artificial fault

V. MEASUREMENTS WITH DIFFERENT FREQUENCIES

The effect of the measurement with higher frequencies is explained with two comparison measurements at 50 Hz and at 400 Hz. Both measurements were executed on the identical slot with the same artificial fault. No changes or modifications were made between the different measurements; the only changes made were to the excitation parameters. The measurement was performed on the small hydro generator with 24 excitation windings described in Chapter III.

As known, the flux is inversely proportional to the frequency, but behaves proportional to the voltage. To compare the two measurements with different frequencies, the excitation voltage was kept the same in the first experiment. Consequently, the flux for the 8-times-higher frequency measurement decreased by a factor of 8.

Vice versa in the second attempt, the flux was kept the same for both measurements, therefore the excitation voltage needed to be adapted accordingly. Table 1 and Table 2 offer an overview of the two different settings.

Table 1

Frequenzy (in Hz)	Excitation voltage (in V)	Flux (in % of φ)	Calibration factor (in mV/A)
50	18,6	4	36,6
400	18,6	0,5	336,7

Measurement with same excitation voltage for both frequencies

Table 2

Frequenzy (in Hz)	Excitation voltage (in V)	Flux (in % of φ)	Calibration factor (in mV/A)
50	18,6	4	36,6
400	148,3	4	336,7

Measurement with same flux for both frequencies

If measured with 0,5% of rated flux at 400 Hz, the highest peak at the defect has an absolute amplitude value of around 400 mA, while at 4% and 50 Hz the peak reaches around 650 mA (Figure 9). Although this is much lower, it needs to be considered, the flux was decreased by the factor of 8 (!).
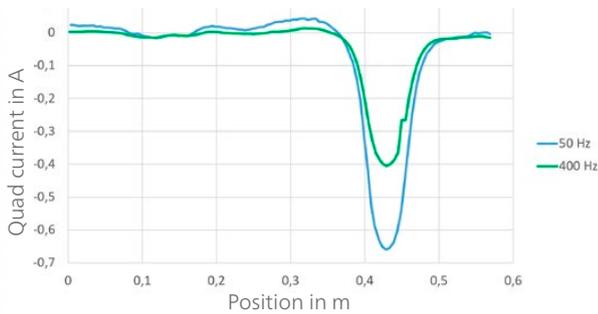
Measurement with the same excitation voltage

Furthermore, we see a lower fluctuation as well around the zero line of the 400 Hz measurement when looking at the "healthy" section of the slot (Figure 10).
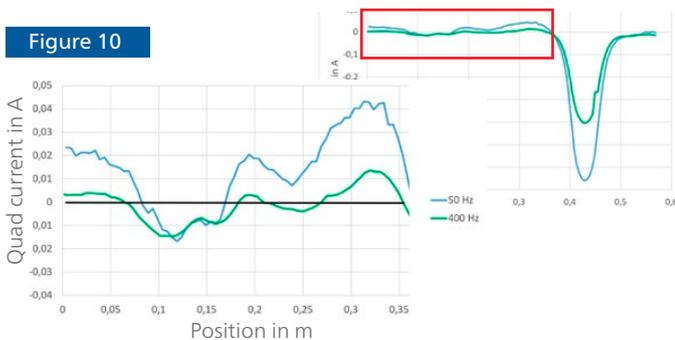
Zoom out of the slot section without the fault

As already assumed from the first experiment, when keeping the flux equal for both frequencies, the picture changes completely, as displayed in Figure 11. . In this case, the amplitude of the 400 Hz measurement is much higher than the 50 Hz measurement at the fault. When comparing this with the measurement in Figure 9, please be aware of the different scaling on the vertical axis.
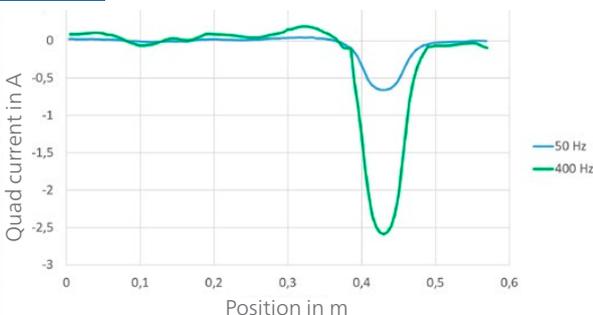
Measurement with the same flux; please note the different scaling at the vertical axis compared to Figure 9.

An absolute limit of frequencies different than rated frequency does not exist and might be the topic of future investigations. Although no limits are existing, the measurement with higher frequencies can be an attractive approach. As the stray flux measurement is also a comparative method, it seems as though measurement spikes on fault locations are clearly visible with higher frequencies.

VI.   DETECTION OF FAULTS DEEPER IN THE STATOR CORE

Faults in the lamination insulation can be detected, even if they are located deeper within the stator core. This is demonstrated on a practical use case, where a motor was in a repair shop due to a phase-to-ground fault in the machine. The protection worked well in this case and tripped immediately, therefore the damage in the machine due to the fault was comparably small and not visible from outside. An endoscopic inspection in each ventilation duct was able to localize the issue. From this investigation it was known that the fault is located on the bottom side of a lower bar. The project leader responsible for the repair wanted to know, if the stator core is affected and needs to be repaired too.
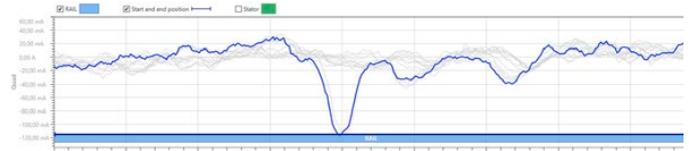
Measurement result of the motor in the repair shop where a problem in the stator core around 800 mm is clearly visible.

Additionally, the operator was convinced that the problem in the stator core was already present before the maintenance work and the damage did not happen during the change of the coil.

VII.   COMPARISON TO RING FLUX MEASUREMENTS

To be able to make statements regarding the comparison of the stray flux measurement and the situation during operation of the machine, a comparison measurement was performed. The test machine was completely renewed so the possibility was there to implement faults and compare it with the full flux test and a thermographic camera.

Figure 13 shows the implementation of these faults, exemplarily on two spots. Different ways of implementing have been tried out.

Figure 13

Example of the fault implementation and black painting to avoid reflection during thermographic measurement.

Depending on the modification technique, not every spot shows a significant increase, for example in temperature raise during the full flux test, as well in the stray flux measurement. Two modifications showed a temperature raise of >10 °C compared to the surrounding, which is considered as critical [1]. These locations could be reliably detected with the stray flux measurement and an amplitude higher than 100 mA too. The heat map with the results of the entire stator as well as the thermographic picture of the two critical spots is displayed in Figure 14. The other spots showed less temperature increase compared to the surroundings. They have been visible as well in the stray flux measurement, as locations with higher stray flux, but remained below the limit of 100 mA.

Figure 14
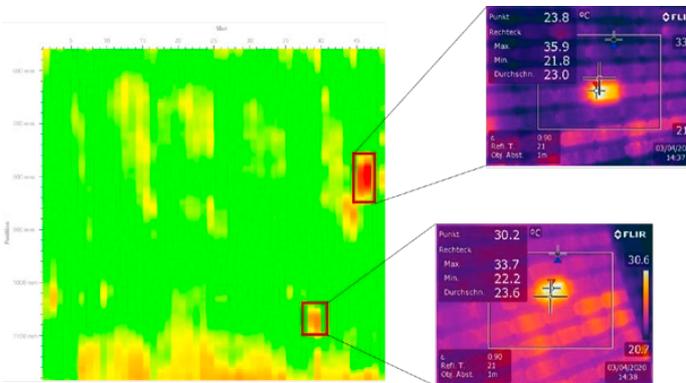
Heat map of the stray flux measurement including thermographic pictures of the comparison measurement with full flux. The two locations with higher temperature raise could be as well identified in the stray flux measurement, where both spots had an amplitude of higher than 100 mA.

VIII.   CONCLUSION

As shown in this paper, the stray flux measurement with the CPC 100 is a reliable method to detect weak spots in the interlamination insulation of stator cores. The portability of the equipment and the easy setup makes the solution interesting for performing on-site measurements as well as workshop applications. Furthermore, a high usability is achieved by a semi-automatic movement of the sensor and the PTM software support.

It could be successfully proven that faults located deeper in the stator core have been detected. Furthermore, the comparison with the high flux measurement showed the same results.

References

1. IEEE Std 56-2016 "IEEE Guide for Insulation Maintenance of Electric Machines," Annex D (informative), September 2016.

2. Cigre brochure 257, "EL CID (ELECTROMAGNETIC – CORE IMPERFECTION DETECTOR) TESTING OF LARGE STEAM-TURBINEDRIVEN GENERATORS", Working group A1.01.06, October 2004

3. [3] Bertenshaw, David Ronald: "STATOR CORE INTERLAMINATION FAULTS AND THEIR DETECTION BY ELECTROMAGNETIC MEANS". Manchester, 2014

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