Utilization of Repetitive Surge Oscillograph (RSO) in the Detection of Rotor Shorted-Turns in Large Turbine-Driven Generators

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***Abstract* – The use of the RSO technique for the detection of shorted-turns in the field winding of large synchronous generators with cylindrical rotors has become more widely accepted in North America in the last few years. The test procedures have been previously described in a number of publications. However, interpretation of the RSO traces haven not been well defined, and the benefits and limitations of its application are not well understood. Using some recent experience, this paper is intended to provide guidance on signal interpretation and to clarify the main advantages and limitations of the application of the RSO testing.**

I. INTRODUCTION

Assessing the condition of high-speed (cylindrical-rotor) turbine-generators has always been a challenge. This is especially true of the field windings, which are largely inaccessible under the wedges and retaining-rings. Limited access for inspection may be available on some rotor windings through radial ventilation holes in the wedges and under the retaining-rings.

The opportunity for tests is equally limited. The copper resistance can be accurately measured, but if a fracture is developing, the test will not reveal the condition, so long as there is good electrical connection at the crack. Groundwall insulation over-voltage test is generally not recommended and the low-voltage insulation resistance ("megger") test mainly relates only to cleanliness and moisture.

Turn insulation shorts are an important and relatively common field winding failure mechanism. In operation, turn shorts may be revealed by low and/or erratic field temperature readings. (But the instrumentation behavior may also just be the result of a defective meter or electrical circuit). The most reliable way of detecting shorted turns in operation is with the use of a *rotor flux monitor*. The probe is a simple, relatively inexpensive device; it will quite accurately tell the number of shorted turns and indicate the coils in which the shorts are located. But installing the probe generally must be done with the field removed and probes have not yet been installed in many generators.

At stand-still, if a significant number of shorts exists, copper resistance will be lower than on the original winding – in proportion to the percentage of shorted turns. But this test gives no information as to location of shorts. Where physical access is available to the copper of the turns or coils, probing for voltage drop or resistance can determine the exact coil (or turn) that is shorted. But performing this test is time-consuming and generally some field disassembly is needed, e.g., retaining ring removal.

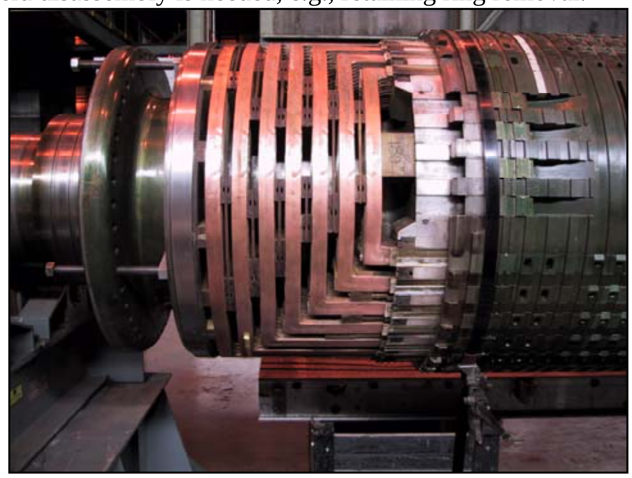

Fig. 1 Typical field endwinding

The Repetitive Surge Oscillograph (RSO) test overcomes many of the above limitations for shorted-turns testing, both at stand-still and with the rotor at speed. The RSO test is the subject of the remainder of this paper.

II. BASIC DESCRIPTION OF THE OPERATION OF THE RSO

Figure 1 above shows the end-section ("overhang" or "endwinding") of a typical cylindrical rotor ("field") winding. Figure 2 shows the middle-section of a *field* winding.

Fig. 2 Typical field winding showing both the middle and end sections. Some of the turns are shown lifted from the slots.

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Both figures above clearly show that a distinguishing feature of cylindrical rotor field-windings is their symmetry. This characteristic is common to all large synchronous cylindrical rotors, belonging to either 2-pole or 4-pole machines. Under operating conditions, the field winding carries a DC current. Thus, the proper circuit representation is simply a resistor. However, if alternating currents flow thru the winding, a complete circuit representation will also include inductances and capacitances.

Inspection of both figures 1 & 2, show that part of the winding (the "middle" section), is in close proximity to the rotor forging. Figure 3 depicts the cross section of a typical slot showing the conducting bars and their proximity to each other and to the forging.

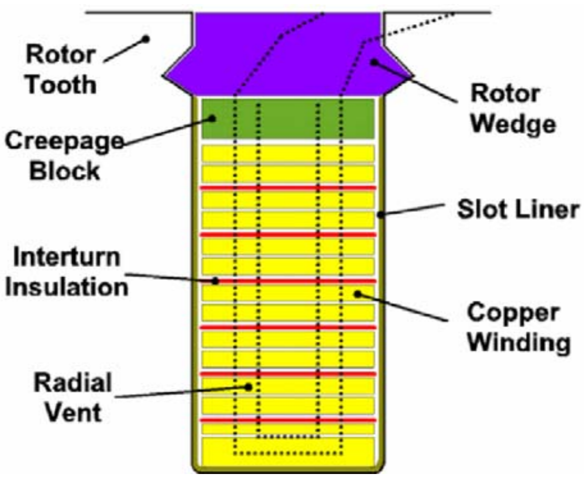

Fig. 3 Cross-section of a cylindrical rotor slot showing the winding conductors and insulation

The proximity between turns exists both in the middle and end sections of the winding, while the proximity to the forging exists only in the middle-section, inside the slot. This geometry results in a winding with resistance, capacitance and inductance that is very specific to each design, but that has some common characteristics to all. Calculation of the circuit components is not simple, but their measurement is. For a low-frequency representation, a *lumped* circuit representation is easily obtained. For high frequencies, a *distributed* circuit representation is required.

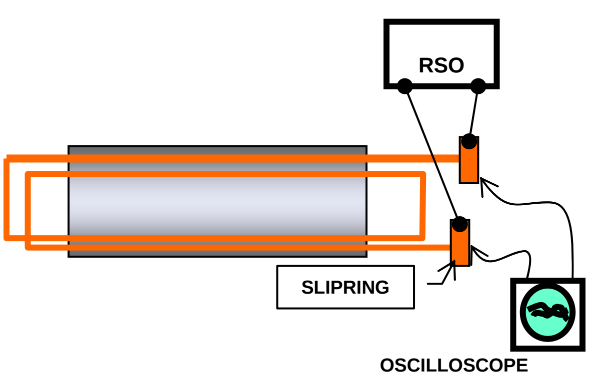

Fig. 4 RSO test arrangement

The RSO is an instrument that injects two identical ("twin") signals – one from each end of the winding. In addition, a built-in, or separate oscilloscope is used to capture the signals at the other side of the winding, and any reflections that occur. Figure 4 shows the typical RSO arrangement, including power source, connections and oscilloscope.

The twin signals generated by the RSO and shown schematically in Figure 5, have a fast rise time equivalent to a high frequency waveform. The impedance presented by the rotor field to this high frequency signal is the *wave impedance* of the R-L-C distributed circuit. From Time Domain Reflectometry theory it is known that a signal encountering an abrupt change in wave impedance will result in a reduced *thru* signal and a *reflected* signal. Given the strong symmetry of the field winding, all thru and reflected signals, in the absence of a shorted turn or a ground, will be almost identical. However, if a discontinuity of the wave impedance, created by a shorted turn or a ground exists, both twin signals will generate different thru and reflected waveforms. The RSO takes advantage of this fact to detect shorted turns and grounds. Because grounds of the field winding can be detected by other means, the RSO main purpose is the detection of shorted turns.

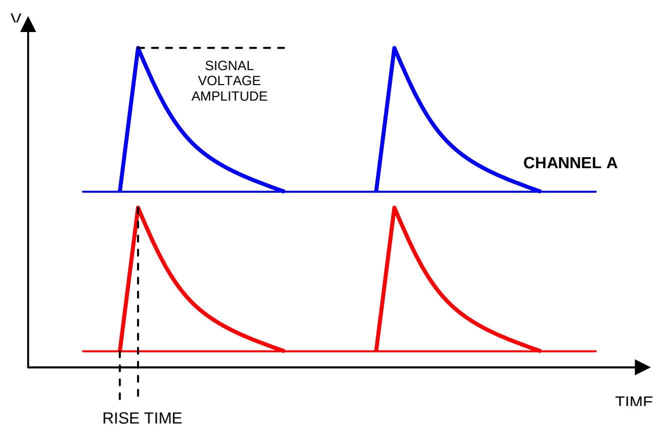

Fig. 5 Twin signals from the RSO

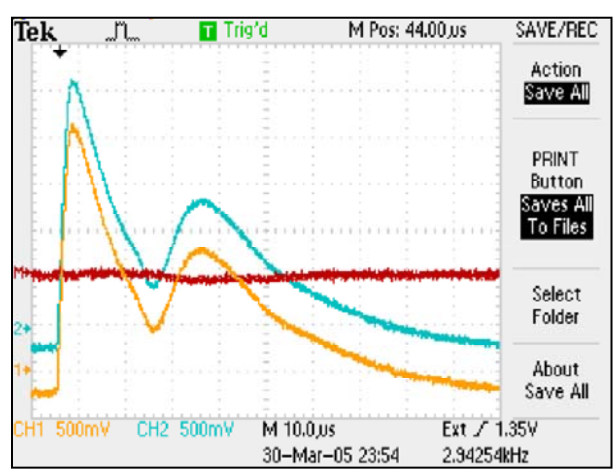

Fig. 6 – RSO twin signals as picked from a rotor winding without shorted turns. The quasi-straight line is the sum of the signals with one of them inverted

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The frequency of the twin signals and rise time are specific to each RSO vendor, thou they are typically in the kHz region with rise times of several microseconds. Figure 6 shows the typical twin signals as picked up from a rotor without winding shorted-turns or grounds.

As shown on Figure 6, it makes it easier to identify the existence of shorted-turns or other anomalies, by inverting one of the signals and summing it up with the other. This can be done in the oscilloscope. The resulting waveform is a straight line, if shorts are not present, or a line with kinks on it, if there are shorted-turns. Figure 7 shows typical traces from a rotor with shorted-turns present.

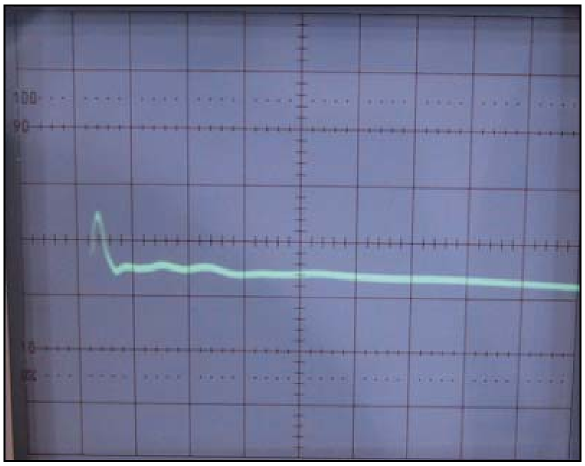

Fig. 7 The waveform shows the summed up signal from a rotor with a shorted-turn.

III. RSO APLICATION ISSUES

As explained in the Introduction above, there are a number of techniques for detecting shorted turns in turbo-generator rotors. The RSO has a prominent place among them. The RSO, first used in the Great Britain in the 1970's, has gradually penetrated North America from the middle 1990's. The RSO's great advantages are: its simplicity use and swift setup and measurement times, as well as the fact all readings can be taken from the collector rings (and the case of brushless units, from the end of the field winding next to the diode-wheel). The main use of the RSO is on rotors standing still, either assembled in the stator or outside. But,as shown below, the RSO can be used on rotating fields with collector rings. This has been done with great success by the authors of this paper and others. This capability is particularly important for those cases where a *rotor flux monitor* is not permanently installed in the airgap.

The RSO cannot pinpoint the exact location of a shorted-turn, although experienced users can develop the dexterity that allows them to identify with high likelihood the coil and pole where a short(s) may be located. Figure 8 shows multiple shorted turns on the first ("small") coils of a rotor. A kink on the resultant curve close to the beginning of the trace indicates a shorted-turn close to one of the sliprings. As the kinks move away from the beginning of the curve, they indicate shorted-turns in the larger coils. (The "small" coil is the coil closest to the pole-face of the rotor, while the "largest" coil is closest to the quadrature axis of the rotor).

It is well known that a large portion of all shorted-turns tend to "disappear" when the rotor is at stand-still. The reason is that those shorts depend on the centrifugal forces encountered while the rotor is turning a high speed.

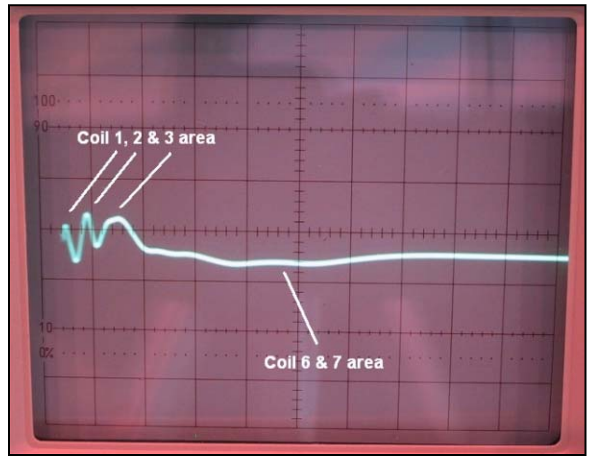

Fig. 8 RSO trace showing multiple shorted-turns

Some of these pressure-dependent short may be detected with the rotor at standing-still, taking measurements at various rotor angles, i.e.: the rotor is rotated by hand and stopped at various angles until it moved a full turn. Often the RSO will detect a short in one rotor angle, and not in others. For those shorts that will completely go away with the rotor standing still, the "spinning RSO test" (describe in Section IV, below) can be carried out.

One concern of is how safe is the RSO to personnel and the field winding insulation. Is there an operator hazard and can the test create shorted-turns or grounds where they didn't previously exist? All RSO instruments generate twin signals in approximately a 5 to 15 volt range, thus presenting essentially no personnel hazard. A typical large 4-pole field, with, say 600 VDC and 400 turns, results in 1.5 volts/turn, and at forcing field condition of 2.5 times rated voltage, it will equal about 3.75 volts/turn. Although the voltage distribution of the RSO signals is not linear, the 5 to 15 volts applied by the RSO to the entire winding are certainly of the same order of magnitude or lower. Also, the source impedance of the RSO instrument is very high resulting in mere milliamps at the most, of current flowing from the RSO, even under a full short circuit. Finally, the low voltage output from the RSO allows testing personnel and maintenance personnel to work on the rotor winding with the RSO connected and operational. This feature is very helpful during some stages of a winding repair or installation, when any mistake resulting in a shorted-turn can immediately be detected and corrected.

One must be careful before calling any kink on the curve a shorted-turn. A winding with extremely distorted turn in the endwinding may exhibit enough impedance asymmetry to result in a somewhat distorted RSO trace. A ground fault will show up as a very large kink, thus making it easy to differentiate from a shorted-turn. Thus, experience is important in the application of this technology.

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IV. SPINNING RSO

Figure 9 shows the RSO measuring setup for testing rotors at speed. It is critical when carrying out an RSO test with the rotor spinning, that all connections to the exciter are open. One proven method is by removing all commutating brushes and installing for the duration of the test one or two brushes per slipring. These brushes must be insulated to the brush-holder. To insulate the brushes, they may be slightly grinded and coated on their side with a thick layer of insulating epoxy paint. Then, the pigtail of the brush is connected to the RSO output and the oscilloscope. The RSO instrument ground must be connected to the spinning shaft either by holding (carefully!) against the shaft a grounded braid on a stick, or by connecting to the shaft grounding brushes. An alternative method to connecting the RSO to the winding is by connecting it to the plus and minus polarities of the brushgear, but opening the circuit from the exciter side (Figure 9).

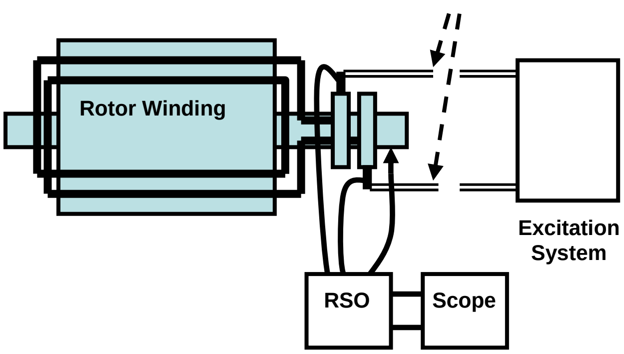

Fig. 9 Measuring setup for a "spinning RSO" test

V. CONCLUSIONS

The RSO is an excellent tool in the bag of tools existing to discover shorted turns. However, like any other tool, it must be used only when applicable, and with the insight of experience. The goal of this paper is to make potential users aware of the capabilities of the RSO, as well as to alert them to its limits.

VI. REFERENCES

EPRI TR-114016: "On-line Detection of Shorts in Generator Field Windings.

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