THE ROTOR FLUX PROBE TEST

1. INTRODUCTION

The **RSO test** is very sensitive and will detect winding faults which do not carry any significant current in normal operation. An alternative test which will only detect **current-carrying winding faults** is known as the **Magnetic Flux probe test** and is carried out with the rotor excited and at speed. The test uses a **flux probe** (a small search coil) mounted in the **air gap** between the **rotor** and **stator** to monitor the **magnetic field close to the rotor surface** to detect current-carrying inter-turn and double earth faults. The test was first described by D.R. Albright, originally of the US General Electric Company and subsequently GeneratorTech Inc. The next 2 figures are taken from a **GeneratorTech** publication.

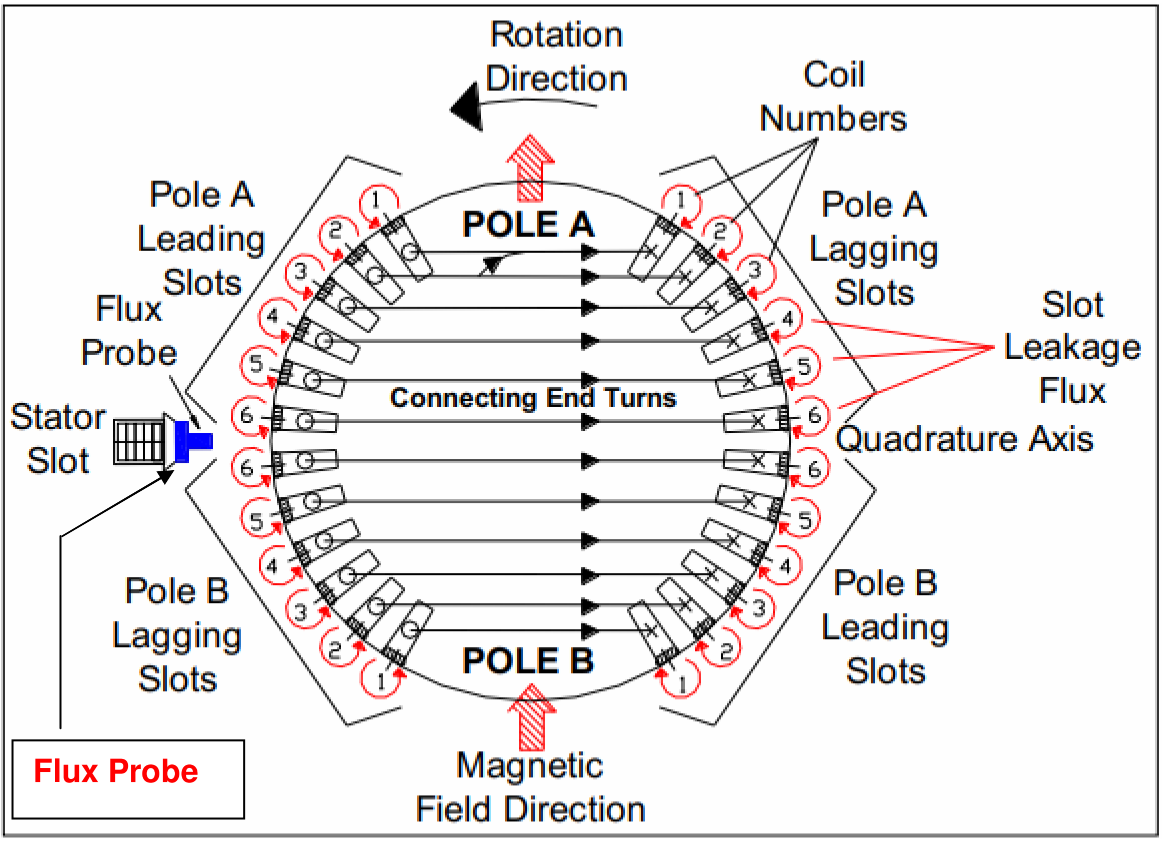

Figure 1.1 Cross-sectional representation of a cylindrical rotor. *

Figure 1.1 shows the cross section of a **2-pole cylindrical rotor** with 6 coils per pole. It also shows the **2 magnetic poles A and B** and a **Flux Probe** mounted on a **stator slot wedge** so that it protrudes into the **air gap** between the stator and rotor surfaces.

As the rotor rotates at 3000 or 3600 rpm (anti-clockwise in the figure above) the rotating magnetic field generates a low-voltage signal, proportional to the rate of change of magnetic field in the **stationary flux probe**, as shown in figure. 1.2.

* From Generatortech publication.

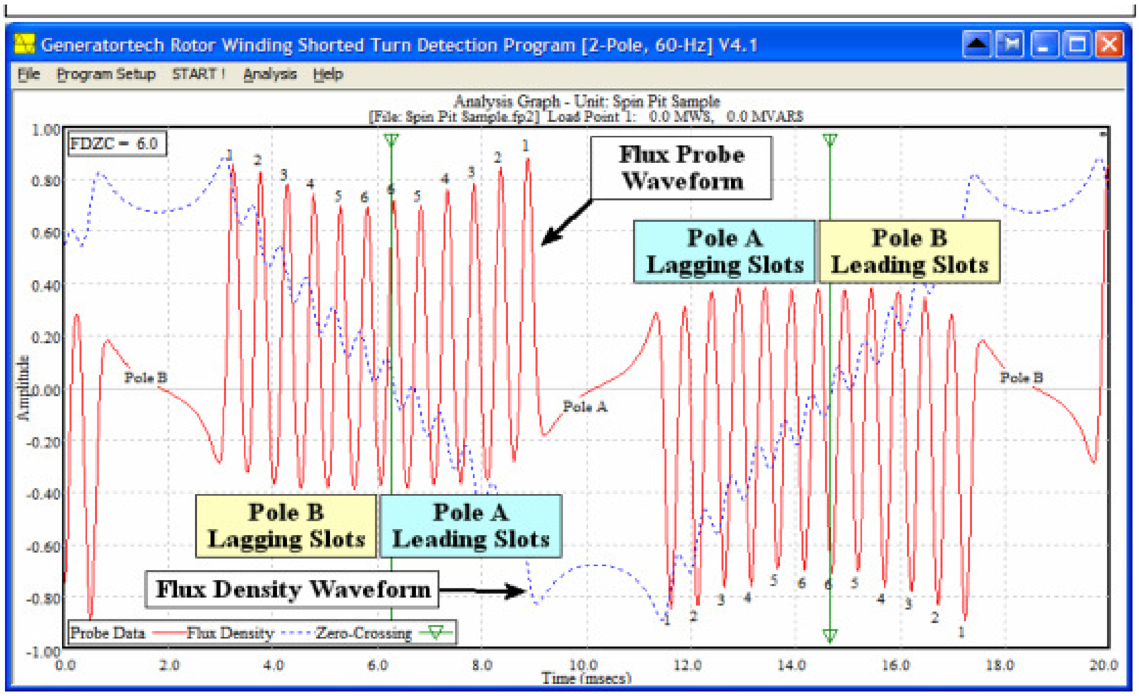

Figure 1.2 Output signal from flux probe *

In the **polar regions** (shown as **Pole A** and **Pole B** in figure 1.2 above), the rotor body is (relatively) uniform magnetically and the **flux probe coil** output varies only slowly as the rotor rotates.

However in the **coil slot regions** between the poles, the **magnetic field path** is **interrupted** by each **coil slot** which has been cut into the **rotor body**. This causes a **magnetic potential** to exist between each slot **"tooth" of** the **rotor body**, and this generates a magnetic **slot leakage flux,** as shown in **red** in figure 1.1.

The **flux probe** is located **close to the rotor surface** and the rapid changes in the magnetic flux between each subsequent coil slot induce a ripple signal at a typical frequency around **2kHz** in the **flux probe output** as shown in figure 1.2. This flux probe waveform is typical of the case where there are no shorted turns in the rotor winding. The figure also shows which parts of the ripple signal result from each set of coil slots associated with the **magnetic poles A** and **B** and their designation as "**leading**" or "**lagging slots**". The **lagging slots** immediately **follow** the pole regions **A** and **B** in time, while **the leading** slots **precede** these same pole regions.

The output signal from the **flux probe** installed in the alternator air gap (or a similar probe located close to the rotor surface for a rotor under test in an overspeed pit) can be processed by a custom instrument (such as the **Rowtest RFM200 Rotor Flux Monitor**) to produce a **nulled waveform** for a **fault-free generator,** as shown in figure 2.1. However, a field winding with a current-carrying inter-turn fault will display a series of peaks in the “nulled” waveform, where the peaks correspond to the position of the faulty coil slot as described later.

The **flux probe measurement technique** has the further advantage over alternative methods in that **continuous on-load monitoring** of the generator is possible and **only current- carrying winding faults are detected.** In addition, a double earth fault (which is an extreme case of an inter-turn fault) will be detected directly if significant fault current flows.

* From Generatortech publication.

2 PRINCIPLE OF OPERATION OF THE "DELAY AND ADD" TEST METHOD

Figure 2.1 below, obtained from a **fault-free generator** having **8 coil slots per pole**. It shows the **voltage waveform** induced in a **flux probe** located in the air gap between the generator rotor and stator, for **one complete revolution of the rotor**. The waveform contains 2 nominally symmetrical and sequential regions X and Y, corresponding to each half-circumference of the rotor centered on the **North-South polar axis**, together with the outputs over the polar regions A and B.

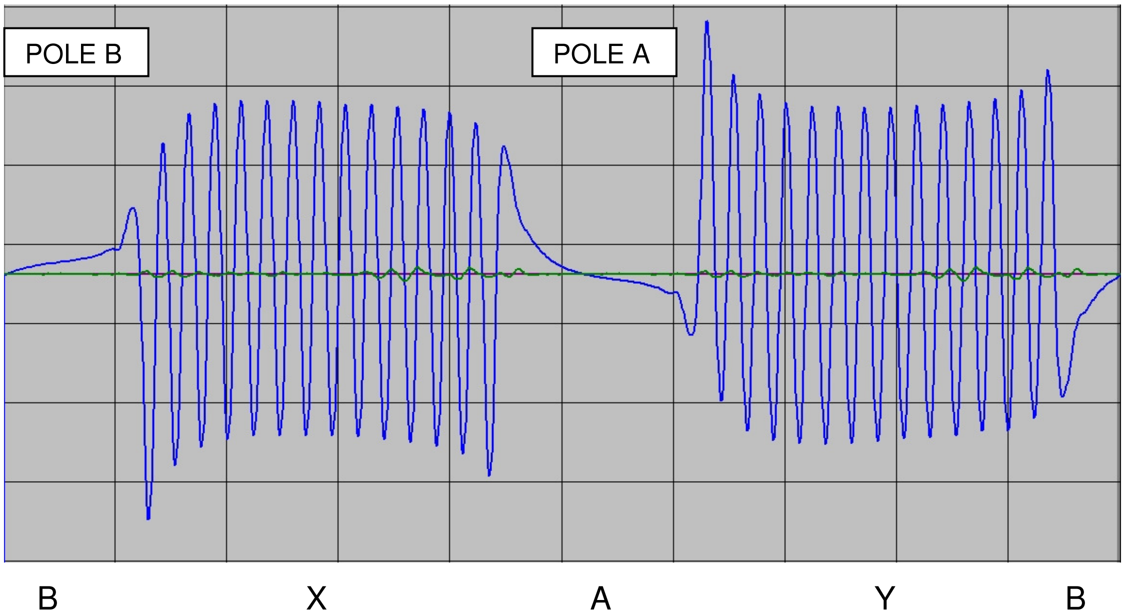

Figure 2.1 Typical search coil waveform for a fault-free rotor

The waveform regions X and Y (containing higher-frequency ripple signals) correspond to the rotor field coil slots located either side of the magnetic poles A and B. The waveform sequence B-X-A-Y-B repeats once per revolution of the generator rotor (nominally 3000rpm for a 2-pole rotor generating a 50Hz output).

Flux probes can be installed either in the **air gap** between the **stator** and **rotor** (for operational generators) or mounted on a **test probe** located near the rotor in an overspeed pit (in manufacturers' or repair works).

The probes can be oriented to monitor either the **radial** or the **tangential (circumferential)** components of the **magnetic leakage flux** produced by the excited rotor winding. The waveform in figure 2.1 is from a **radial field** flux probe and in this case, the **waveform Y** has the **opposite polarity** to that of **waveform X**.

The flux probe test equipment typically digitises and compares the search coil waveforms for the A and B regions and displays the **difference between them** on the screen of a computer. For both **radial** and **tangential flux probes**, this process is carried out by delaying the search coil waveform by 180 degrees and either adding or subtracting the delayed waveform to/from the undelayed one.

For a perfect winding, the X and Y waveforms should be similar (although of opposite polarity depending on the type of search coil in use) so the difference or sum waveform should be zero. This is known as the "**delay and add**" method. The green waveform in figure 2.1 is the result of adding the A pole half-waveform to the B pole half-waveform delayed by one half revolution.

3 DETAILS OF FLUX PROBE WAVEFORMS

The flux probe waveforms have the following properties depending on which type of search coil is used in the probe. In the figures shown in this section, unless stated otherwise, the waveforms were synthesised using an electronic signal generator to approximate to typical real flux coil waveforms.

3.1 TANGENTIAL FIELD FLUX PROBE

For a tangential magnetic field search coil, the **group Y** waveform is nominally identical to and has the same polarity as the is **group X** waveform and so the **delayed waveform** must be **subtracted from** the original waveform to produce cancellation (a nulled waveform).

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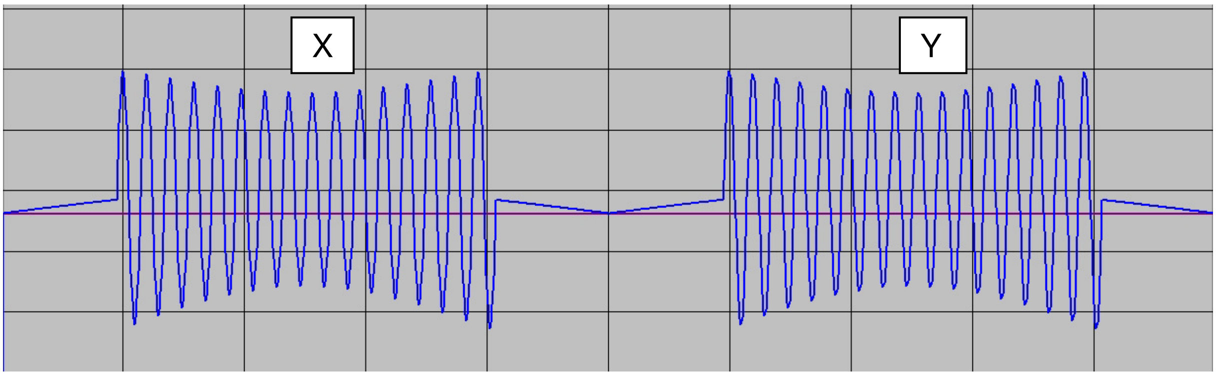

Figure 3.1 Simulated tangential search coil waveform

3.2 Radial magnetic field search coil. (Siemens type)

For a radial magnetic field search coil, the **group Y** waveform is the **inverse** of the **group X** waveform and so the **delayed waveform** must be **added to** the original waveform to produce cancellation (nulled waveform).

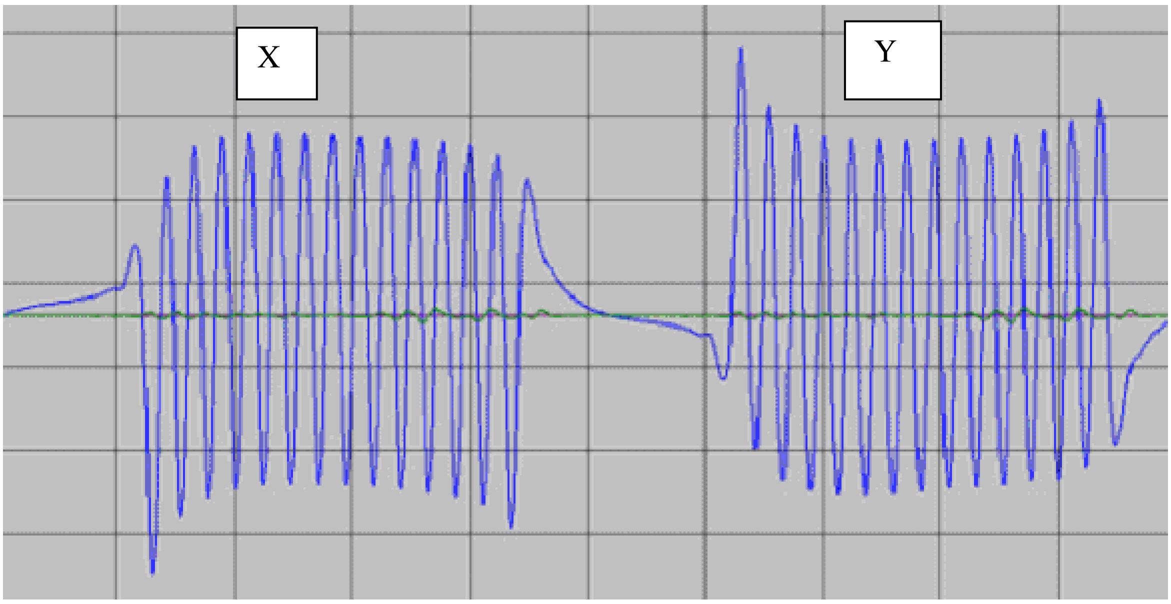

Figure 3.2 Measured radial search coil waveform

In figure 3.2, the blue trace is the search coil waveform and the green trace is the difference waveform obtained after delaying and summing.

4 EXAMPLE WAVEFORMS

4.1 RADIAL FLUX PROBE

The following examples show simulated flux probe waveforms for a fault-free rotor winding (a) and one containing a major interturn fault (b) (blue waveforms). Figure (c) shows the "nulled" (red) waveform.

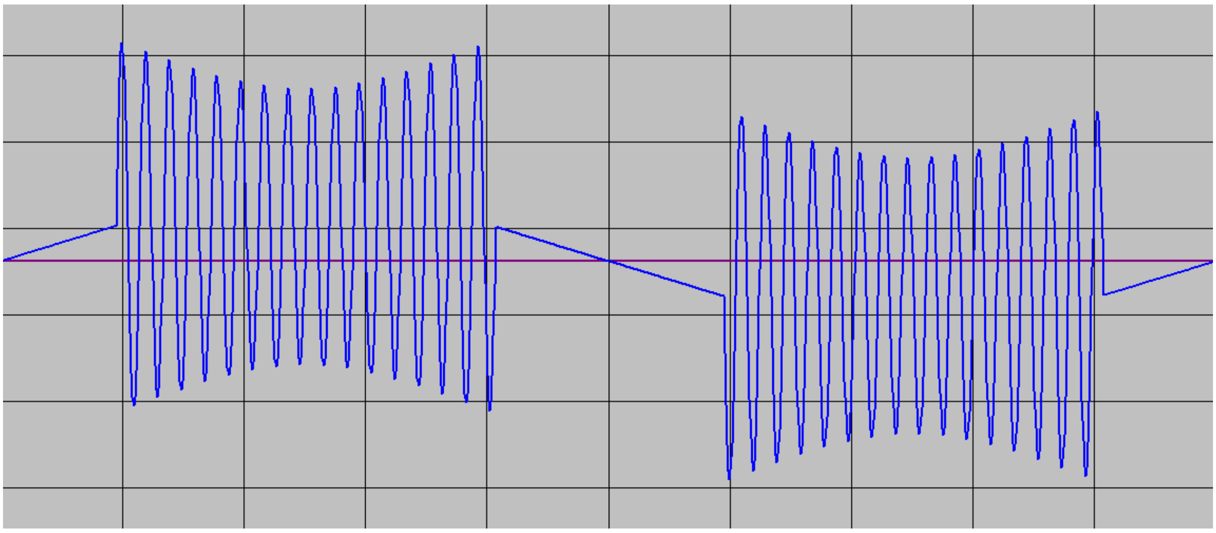

Figure 4.1(a) Simulated radial flux probe waveform for a fault-free rotor.

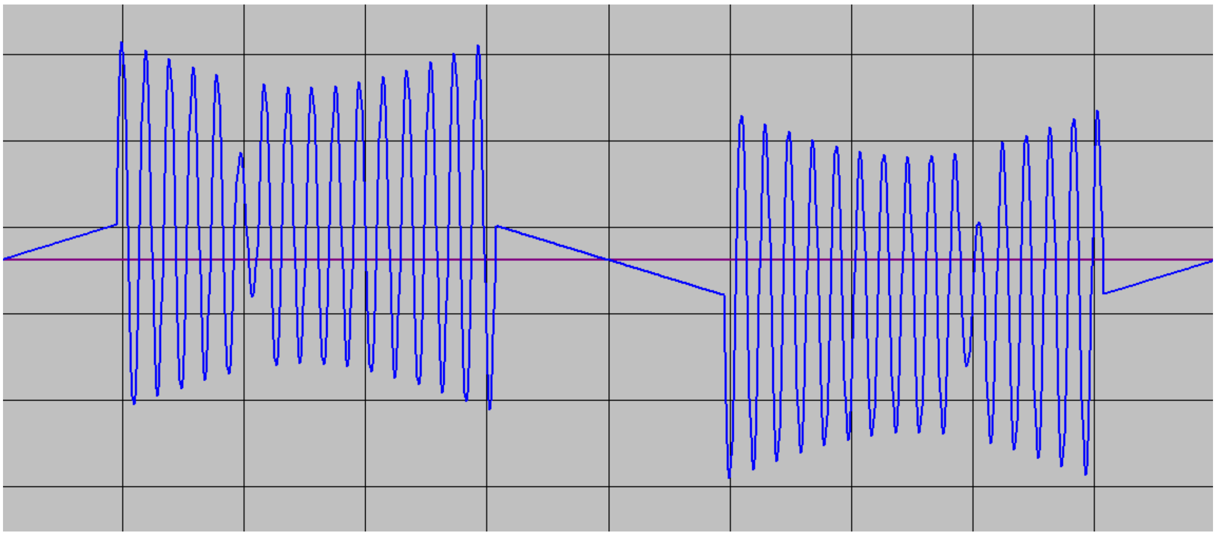

Figure 4.1(b) Simulated radial flux probe waveform with shorted turns in 6th coil from one pole

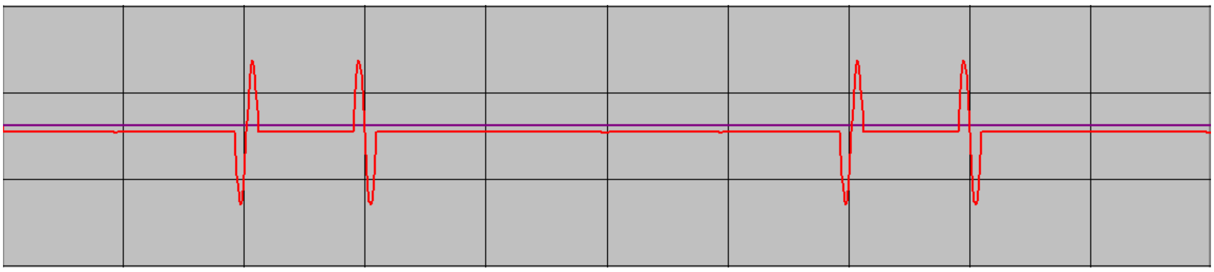

Figure 4.1(c) Applying delay and add method to waveform in 4.1(b) to identify location of shorted coil

4.2 TANGENTIAL FLUX PROBE

The following examples show simulated tangential flux probe waveforms for a fault-free rotor winding (a) and one containing a major interturn fault (b) (blue waveforms). Figure (c) shows the "nulled" (red) waveform.

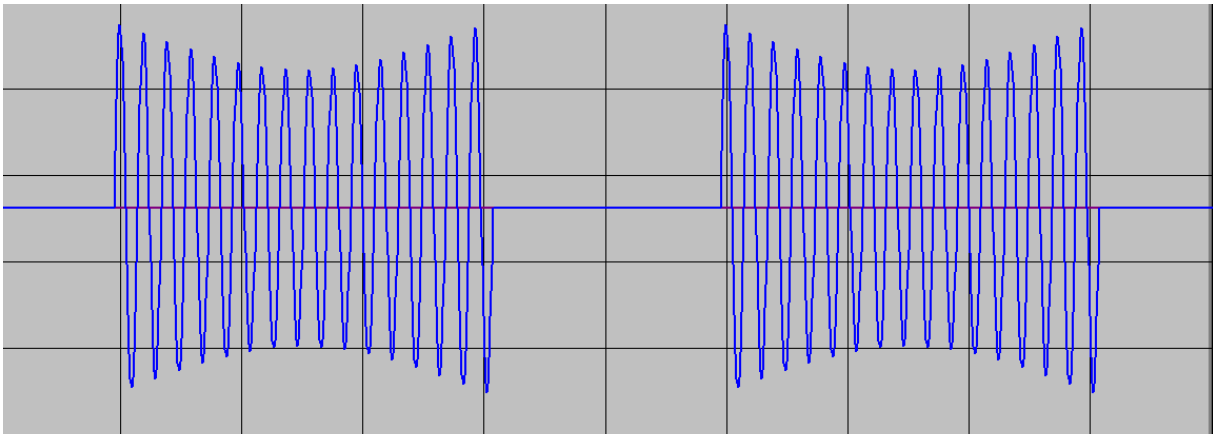

Figure 4.2(a) Simulated tangential flux probe waveform for a fault-free rotor.

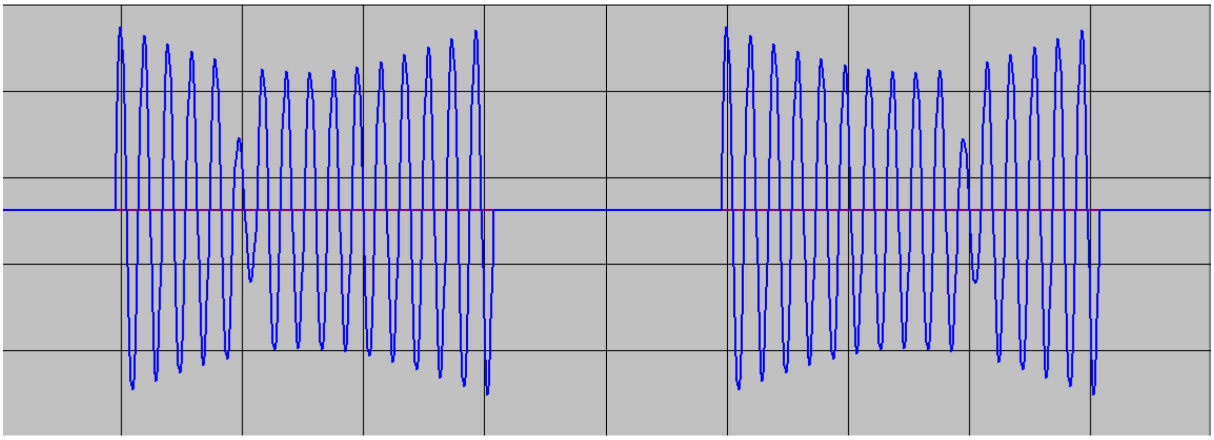

Figure 4.2(b) Simulated tangential flux probe waveform with shorted turns in 6th coil from one pole

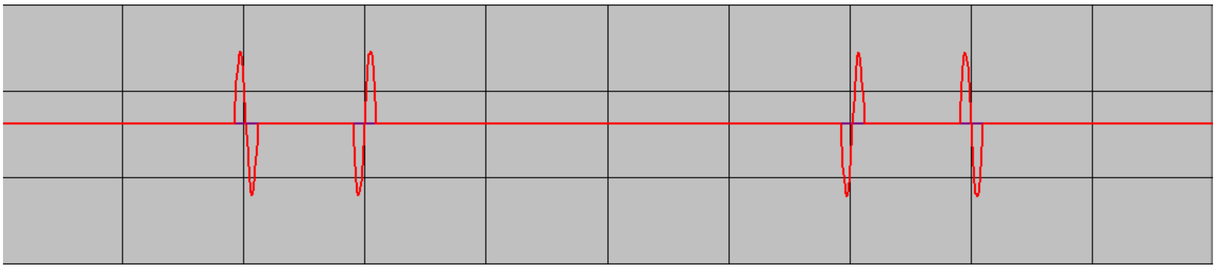

Figure 4.2(c) Applying delay and subtract method to waveform in 4.2(b) to identify location of shorted coil

Note that in this case, the nulled waveform is obtained by subtracting the delayed waveform, as the tangential flux probe produces the same polarity waveforms for both poles..

5 FLUX PROBE TESTING IN AN OVERSPEED PIT

The flux probe test can be also carried out in a manufacturer or repairer's works with the rotor removed from its stator. In this case, only limited excitation can be applied to the rotor because of the high magnetic fields which would be produced.

One problem which can occur results from the unwanted effects of any residual magnetism in the rotor core. These effects can be largely corrected as described in the next sections.

6 EFFECTS OF RESIDUAL MAGNETISM

When a rotor is tested outside the stator (eg in an overspeed/balancing pit), only limited excitation can be applied to the rotor winding to avoid the magnetised rotor from interacting with local steel objects (bedplates etc.).

Experience has shown that with no excitation, the rotor retains some residual magnetism and this affects the shape of the search coil waveforms obtained with low values of excitation current (<50A).

These problems can be corrected by capturing the search coil waveform with the rotor winding unexcited as a reference (Residual magnetism) waveform and subtracting this waveform from the waveform obtained when the rotor is excited with a modest current (excited waveform).

The waveforms in Figure 6.1 were obtained for a fault-free rotor (130 MW, 7 coils/pole) excited under test conditions with a restricted current of 27A at 3000 rpm..

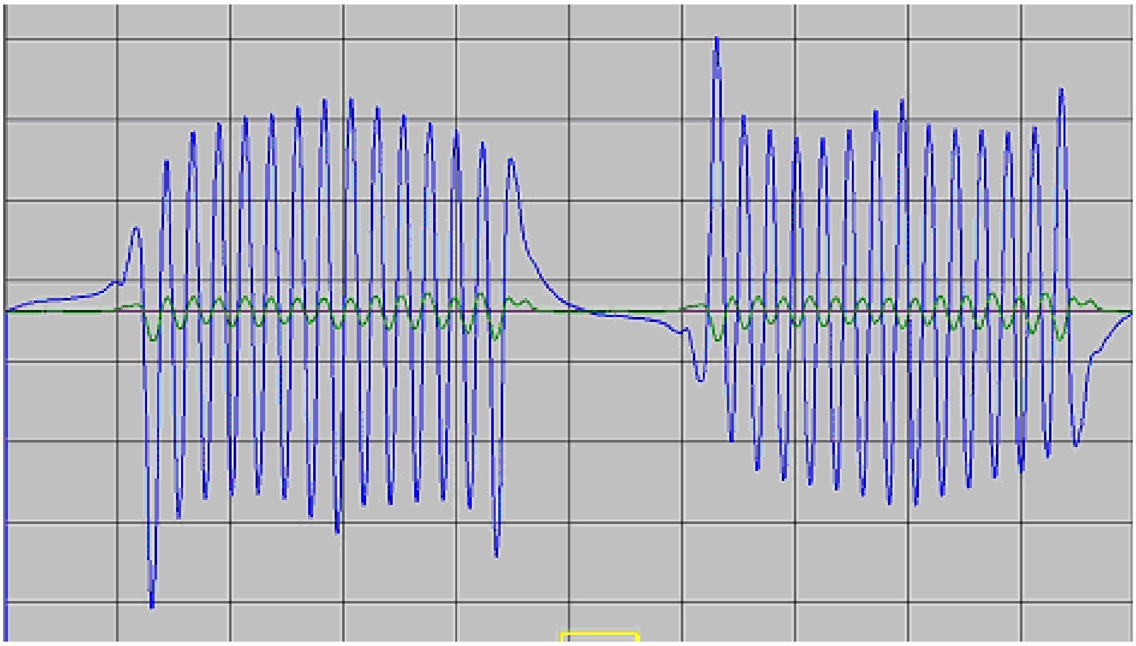

Figure 6.1 Uncorrected search coil waveform

The search coil waveform is shown in (**Blue**) The **Green** difference trace is the result of using the delay and add technique described above. Note that this difference waveform has significant amplitude, even though the rotor winding is fault-free. This effect is caused by the residual magnetism in the rotor body.

In figure 6.2, the residual magnetism signal (obtained by running the rotor with no excitation) has been subtracted from the excited search coil waveform of figure 2.3. Note that the Green difference trace is now almost perfectly cancelled.

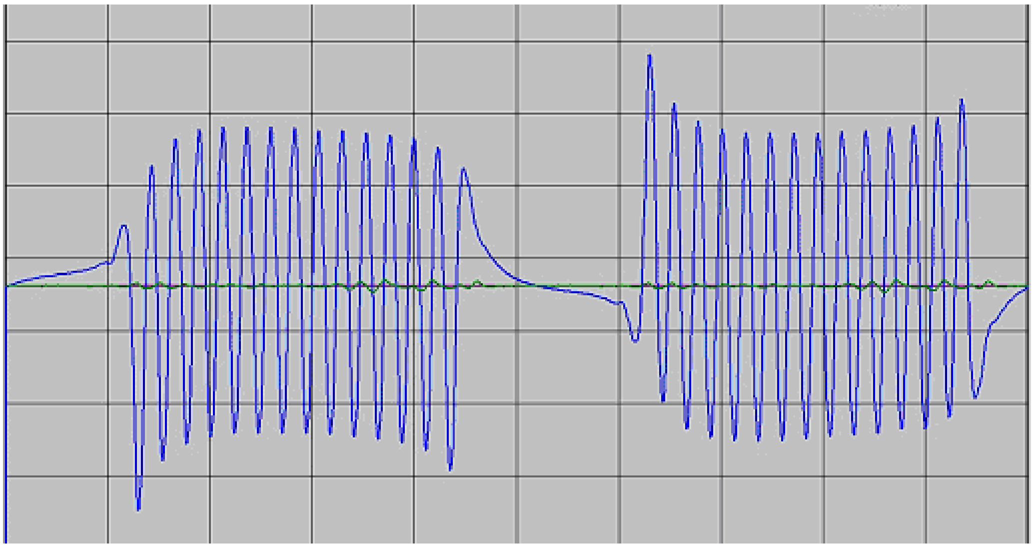

Figure 6.2 Search coil waveform corrected for residual magnetism

7 COMMENTS

The RSO and Flux Probe tests are complementary test methods and both are widely used for testing the rotors of large electricity generators.