

# ROTOR FLUX PROBE CALIBRATOR AND WAVEFORM GENERATOR TYPE RWG100



## USER MANUAL

V 1.01

JANUARY 2022

This **User manual** describes the use of the **Rowtest RWG100 flux probe waveform generator and calibrator**.

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## OVERVIEW

The Rowtest **RWG100** is a custom signal generator which can be programmed to generate **simulated Rotor flux probe search coil waveforms**. It operates as a stand-alone signal generator which can also be programmed with new waveforms using custom software running on a PC. The waveforms can be either simulated or actual flux probe waveforms provided these are in standard **Rowtest** data file format. The **RWG100** unit can be used to check the **calibration, accuracy and functionality** of **Rotor flux coil analysis equipment** and also as a **teaching aid** for new users of this equipment.

## LIST OF EQUIPMENT SUPPLIED

- 1 x RWG 100 Waveform Generator.
- 1 x 5V External USB Power supply for above.
- 1 x USB printer lead for power supply.
- 1 x USB to RS232 Programming lead and installation disk.
- 2 x Coaxial BNC Oscilloscope leads.
- 1 x Instruction manual.
- 1 x Padded Storage bag
- 1 x Custom RWG100 software package on CD.

## **CONTENTS**

### **0. QUICKSTART GUIDE**

#### **1. A BRIEF INTRODUCTION TO LARGE TURBOGENERATOR ROTORS**

#### **2. AN OVERVIEW OF FLUX PROBE TESTING**

#### **3. OVERVIEW OF THE RWG100 WAVEFORM GENERATOR**

#### **4. RWG100 WAVEFORM GENERATOR DETAILS**

#### **5. SOFTWARE OVERVIEW**

#### **6. GENERATING A SIMULATED FLUX PROBE WAVEFORM**

#### **7. VIEWING AND CHECKING THE SAVED FLUX PROBE WAVEFORMS**

#### **8. PROGRAMMING A NEW WAVEFORM FILE INTO THE RWG100**

#### **9. COMMENTS ON RESULTS FOR REAL DATA.**

#### **10. SOFTWARE INSTALLATION ON A NEW WINDOWS PC**

#### **11. RWG100 SPECIFICATION**

### **12. APPENDICES**

#### **APPENDIX 1**

##### **Operating Principles of Large Electrical Generators**

#### **APPENDIX 2**

##### **Flux probe (search coil) tests**

## 0. QUICKSTART GUIDE

This **Quickstart section** explains how to set up the **RW100** as a stand-alone waveform generator and view the waveforms on an oscilloscope or similar equipment. In this mode, the **RWG100** operates as a **stand-alone waveform generator** controlled by its **front panel** controls.

### 0.1 SETTING UP THE EQUIPMENT

Connect the **USB printer lead** supplied to the power input socket on the rear panel of the **RWG100** unit and to the **USB-type 5VDC power supply**. This is the only connection required to the rear panel of the unit in **stand-alone** mode.



Figure 0.1 Rear panel of RWG100

Connect one of the supplied **coaxial leads** between the **Oscilloscope External trigger input** and the **Ref output** BNC connector on the **RWG100** front panel.

Connect the **second coaxial lead** between the **Oscilloscope Channel 1 input** and the **Waveform output** BNC connector on the **RWG100** front panel.



Figure 0.2 Front panel of RWG100

## 0.2 DETAILS OF THE RWG100 FRONT PANEL CONTROLS AND CONNECTORS

The **RWG100 front panel** is shown in figure 0.2.

A **rotary switch** selects one of **8 pre-programmed waveforms** and an additional **toggle switch** extends this to a further 8 waveforms (16 in total).

A **50/60Hz selection switch**, controls the **simulated rotor rotation frequency** of the output waveform. This frequency derived from an internal clock.

The simulated **flux probe waveform** output is via a **BNC coaxial connector** on the front panel.

The waveform output can be switched on and off by an **output enable** toggle switch and its **amplitude** (+/- 3V max ?) is adjustable by an output potentiometer.

A once per revolution **Reference pulse** (+5V nominal) is also provided at a second BNC connector for oscilloscope triggering purposes etc.

The **RWG100** is powered from an **external 5V USB mains power supply** via a standard **USB printer lead** which connects to a **USB socket** on the **RWG100 rear panel** shown in figure 0.1.

## 0.3 DETAILS OF PRE-PROGRAMMED WAVEFORMS

The following **simulated flux probe waveforms** have been programmed into the **switch positions 1 to 8**. In all cases, the faulty coil is **number 6** from one pole and the 50Hz (**Power frequency**) component value is 50% of the **flux leakage** component (see section 2.2 for further information).

The **fault percentage** means the nominal percentage of the turns in each coil which are fully-shortened. So for a coil of 10 turns, a 20% fault means that 2 complete turns are shorted.

These **accurate waveforms** can be used to **calibrate flux coil analysis equipment** and also for demonstration purposes.

The pre-programmed simulated waveforms are as follows:

<b>Switch position 1.</b>	<b>Fault level %</b>
1	0 (No fault)
2	1
3	2
4	5
5	10
6	20
7	30
8	50

In addition, a number of **measured flux coil waveforms** have been programmed in switch locations 9-11.

## 0.4 VIEWING THE WAVEFORMS ON AN OSCILLOSCOPE

Set the rotary **Waveform select** switch to **position 1** and the associated **range extension toggle switch** to **1-8** (the **UP** position).

Turn the **Output level** control **fully clockwise**

Turn **ON** the **output toggle switch**.

Turn **ON** the **5V main power supply**

Turn **ON** the **Supply on switch** on the **RWG100 front panel**.

Set the **frequency switch** to **50Hz (fully UP)**

Set the **oscilloscope trigger** input to **external**

Set the oscilloscope **vertical gain control** to **2V/division**

Adjust the **oscilloscope controls** to obtain a stable waveform, which simulates a **fault-free** rotor (switch position 1).

The other programmed waveforms for various fault levels can be similarly viewed by rotating the **Waveform select** switch.

## 0.5 THE NEXT STEPS

This section has explained the basic operation of the **RWG100** equipment. Subsequent sections explain the background to **rotor flux coil testing** and give detailed information about the use of the custom software supplied for generating and viewing new simulated waveforms and how these are programmed into the **RWG100** using a standard laptop PC using the **RWG100 custom software**.

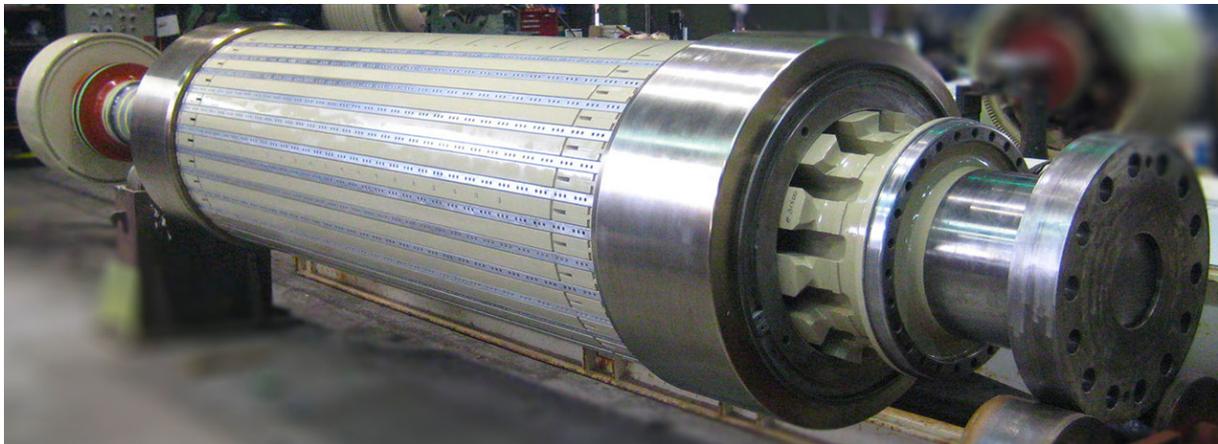
## 1. A BRIEF INTRODUCTION TO LARGE TURBOGENERATOR ROTORS \*\*

A typical large (eg 500MW) electricity generator (alternator) consists of a stationary 3-phase stator winding (the **Stator**) which interacts with a magnetic field produced by a rotating cylindrical electromagnet (the **Rotor**). This generates a high-voltage (typically 25kV) alternating voltage at 50 or 60Hz from insulated conductors located within the laminated stator core. The rotor is normally driven by a steam or gas turbine.

The cylindrical rotor is located inside the stator, with a radial air-gap of a few cm between them and rotates at high-speed (eg 3000rpm) in normal operation. The rotating magnetic field is produced by a direct current (typically 3000 Amps for a large generator) which flows through 100-200 turns of partially-insulated copper bars contained within field coils located in pairs of radial slots machined into the solid cylindrical steel rotor forging.

A rotor can have 2 or more **magnetic poles** and these determine the relationship between the **rotor speed of rotation** and the **supply frequency** generated. For example, the frequency generated by a 2-pole rotor will equal the number of rotations per second, while for a 4-pole rotor, the frequency generated will be 2 x the number of rotations per second etc.

The rotor is constructed from a large cylindrical steel forging into which are machined approximately 14 to 16 pairs of radial slots. Each pair of slots house one field coil of the winding and typically contain 7-20 turns of partially-insulated copper bars connected in series. All of the field coils are also connected in series.



**Figure 1.2 A cylindrical turbo-alternator rotor**

The field coils are subjected to very large centrifugal forces during normal operation and this can cause failure of the coil insulation, resulting in **short circuits** between **adjacent turns** or to ground. The **flux probe test** can detect current-carrying **inter-turn faults** and can be used during normal operation of the generator if flux probes have been previously installed. It can also be used in a manufacturer's or repairer's works with the rotor removed from the generator.

\*\* Further detailed information about the construction of cylindrical turbogenerator rotors can be found in **Appendix 1**.

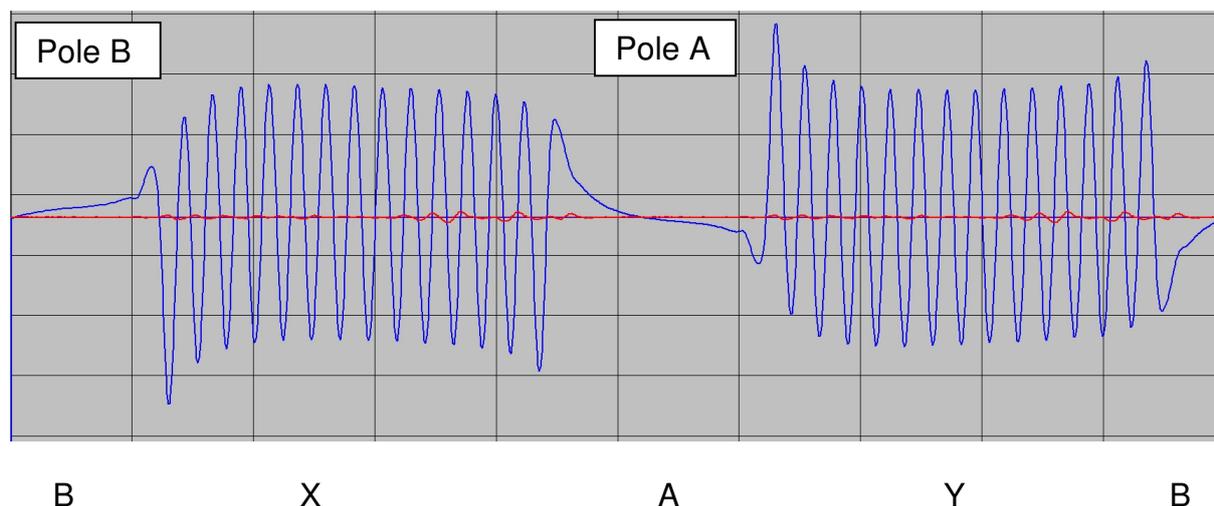
## 2. AN OVERVIEW OF FLUX PROBE TESTING \*\*\*

### 2.1 ROTOR FLUX PROBES

A **rotor flux probe** contains small **magnetic field search coils** and is located in the air-gap between the stator and rotor of large electricity generators. Its purpose is to detect and locate inter-turn faults in the rotor field winding. **Flux probes** usually contain **2 coils**, one to measure the **radial component of the magnetic field density** (flux) generated by the rotor and the other to measure the **tangential field component**. As supplied, the **RWG100** simulates **Radial** flux probe waveforms.

### 2.2 FLUX PROBE WAVEFORMS

The **Blue waveform** in Figure 2.1 below, obtained from a fault-free generator having 7 coil slots per pole, shows the voltage waveform induced in a flux probe coil located in the air gap between the generator rotor and stator, for one complete revolution of the rotor. It contains 2 nominally symmetrical and sequential waveform groups X and Y corresponding to each half-circumference of the rotor located between each of the magnetic poles. A and B.



**Figure 2.1 Typical radial flux 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 surface in an overspeed pit (in manufacturers' or repair works).

\*\*\* Further detailed information on **flux probe testing** is given in **Appendix 2**.

The voltage signal (waveform) which is induced in each **flux probe coil** is made up from **2 main magnetic field components**:

1. A component (1) due to the **magnetic leakage field** due to the coils in the slots. This has a ripple frequency in the range 2 - 3 kHz.

2. A component (2) caused by the **main rotor excitation magnetic field** (which is typically a **50 or 60Hz power frequency** distorted sine wave), together with a further field contribution from currents in the stator (**Power frequency fields**) .

As the **flux probe** is moved closer to the rotor surface, **component 1** dominates and as the coil is moved **towards the inner stator surface**, **component 2** starts to dominate.

The form of the signal picked up by the flux probe therefore depends on the **proximity** of the coil to the rotor but also depends on the phase angle of component 2 relative to the rotor, which varies with the load on the generator.

Flux probe analysis test equipment typically digitises and compares the flux probe waveforms for the X and Y regions using a computer. One analysis method delays the main flux probe waveform by 180 degrees and adds the delayed waveform to the undelayed waveform.

For a perfect winding, the X and Y waveforms should be similar (although of opposite polarity) so the **Difference** waveform, obtained by summing the delayed and undelayed waveforms should be zero. This is known as the "**delay and add**" method. **The Red waveform** in figure 2.1 is the result of adding the X group half-waveform to the Y group half-waveform delayed by one half revolution.

This method has the advantage that if the rotor winding is completely fault-free and symmetrical, the resulting **Difference waveform** will be a simple **horizontal line (shown in red in figure 2.1)**. Furthermore, the effects of Component 2 (the power frequency field) are nulled out and further gain can be used to view the **Difference waveform** in more detail.

The following examples show the results expected from a **Radial field** flux probe.

### 2.3. Radial magnetic field search coil.

For a radial magnetic field flux probe, 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 (the **Difference waveform**). In figure 2.1 the **blue trace** is the **Flux probe** waveform and the **Red trace** is the **Difference** waveform obtained after delaying and summing.

## 2.4 EXAMPLE WAVEFORMS

The following examples in Figure 2.4 show **simulated flux probe waveforms (Blue)** for a fault-free rotor winding (a) and one containing a major interturn fault (b). Figure (c) shows the **Difference (Red)** waveform for the faulty waveform of figure 2.4(b) plotted separately for clarity. This simulated rotor has 8 coils in each half-winding.

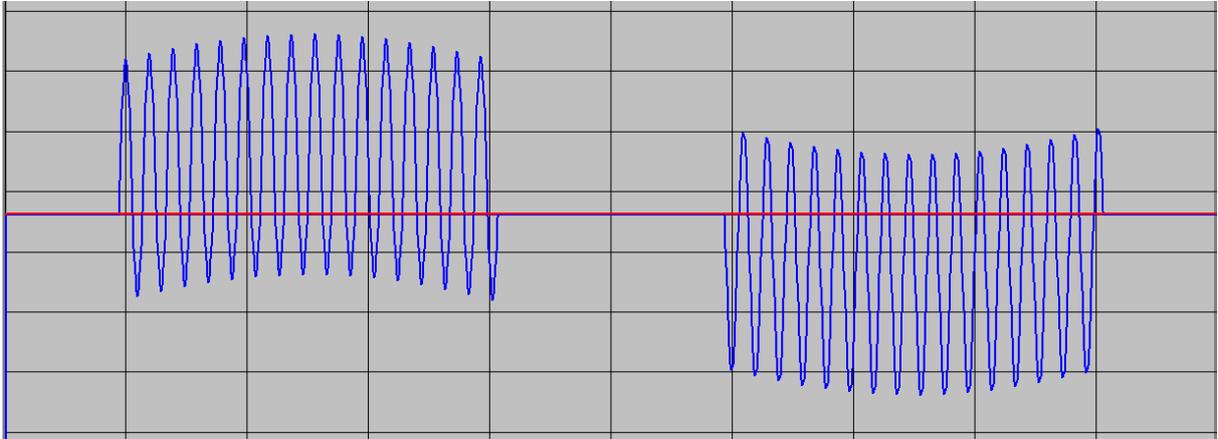


Figure 2.4(a) Simulated radial flux probe waveform for a fault-free rotor.

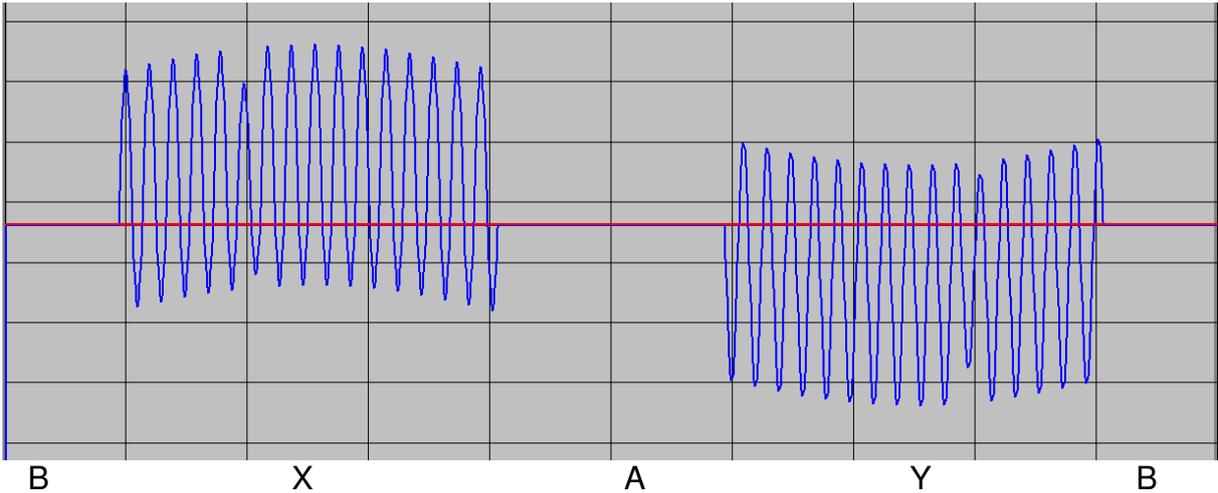


Figure 2.4(b) Simulated radial flux probe waveform with 20% of turns shorted in 6th coil from first pole (B)

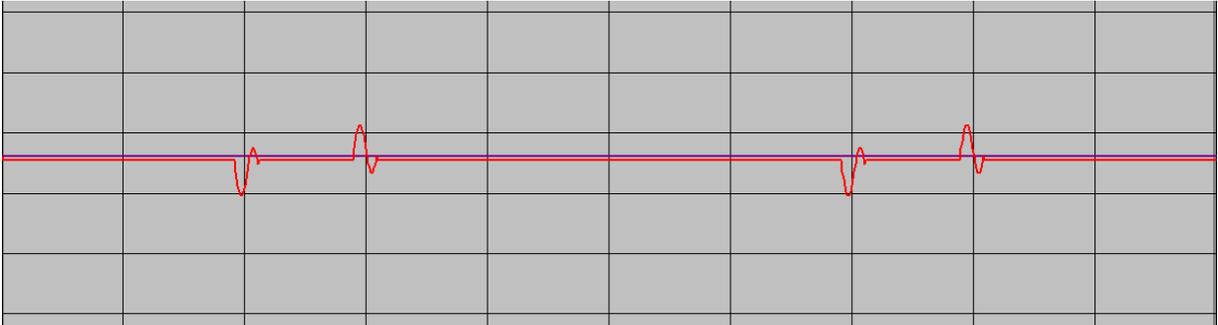


Figure 2.4(c) Difference waveform obtained by applying delay and add method to waveform in 2.4(b) to identify location and magnitude of fault in coil 6.

### 3. OVERVIEW OF RWG100 WAVEFORM GENERATOR

The **RWG100** is a custom programmable signal generator which generates **simulated Rotor flux probe search coil waveforms**. It operates as a **stand-alone signal generator** and can be used for **calibrating** and checking the **accuracy** of rotor **flux probe analysis equipment**. It can also be programmed with new waveforms using custom software running on a PC.

Some of the information in this section has already been given in the **Quickstart** section but is repeated in sections 3 and 4 for completeness.

#### 3.1 OPERATING MODES

The **RWG100** can operate in either a **Local** or **Remote** Mode. In both modes, the **RWG100** is powered from an external standard 5V USB power supply.

##### 3.1.2 STAND-ALONE (LOCAL) MODE

In **Local** mode, the **RWG100** operates as a **stand-alone waveform generator** controlled by its **front panel** controls. This is the **default mode** of operation when the **RWG100** is not connected to a PC.

A **50/60Hz selection switch**, controls the simulated rotor rotation frequency of the output waveform. This frequency is derived from an internal clock.

A **rotary switch** selects one of 8 pre-programmed waveforms. An additional **toggle switch** extends this to a further 8 waveforms (16 in total).

The simulated **flux probe waveform** output is via a BNC coaxial connector on the front panel. The waveform output can be switched on and off by an **output enable** toggle switch and its **amplitude** (+/- 5V max) is adjustable by an output potentiometer.

A once per revolution **Reference pulse** (+5V nominal) is also provided at a second BNC connector for oscilloscope triggering purposes etc.

##### 3.1.2. REMOTE (PROGRAMMING) MODE

The **Remote** mode allows new waveforms to be programmed into the unit from a PC running custom **Rowtest** software which sends commands to the **RWG100** via a **USB/RS232 link**.

## 4. WAVEFORM GENERATOR DETAILS

### 4.1 FRONT AND REAR PANEL CONTROLS



Figure 4.1.1. Front panel controls



Figure 4.1.2 rear panel

Figures 4.1.1 and 4.1.2 show the front (top) and rear panels of the **RWG100**.

The **RWG100** is powered from a standard 5V USB mains adapter by connecting it via a USB printer lead (5V) + to the USB socket on the rear panel.

The rotary **waveform select** switch has **8** positions and is only functional in the default **Local mode**. An extra **toggle switch** extends the total number of waveforms that can be selected to **16**.

In **Local mode**, the **Waveform select** rotary switch on the Front Panel selects **waveforms 1 to 8** with the **toggle switch UP** and **waveforms 9 - 16** with this switch **DOWN**. Neither switches are operational in **Remote mode**.

The **50/60Hz rotation frequency** select toggle switch has a **centre-off position**. This is used for production test purposes only.

The **Flux probe waveform** is output to a **BNC connector** and is enabled by a **toggle switch on the front panel**. Its **amplitude** is controlled by an **Output level** potentiometer.

A once per revolution **5V square wave reference signal (50/60 Hz)** is available at a **second BNC connector**. This should be connected to the **external trigger** input of the oscilloscope to ensure that the displayed waveform starts at the centre of one of the poles as described later.

## 4.2 OPERATION IN LOCAL MODE MODE

The following instructions assume that a number of **flux probe waveforms** have already been pre-programmed into the unit.

Connect the power lead to a 5V USB power supply and switch on the **Supply switch**. The **front panel LEDs** should be in the following states:

### 4.2.1 FRONT PANEL LED STATUS IN LOCAL MODE

The following LEDs will be lit in **LOCAL** mode:

#### LOCAL MODE

(**NO EXTERNAL REF**) Only if freq toggle switch is in centre position)

#### SUPPLY ON

### 4.2.2 SETTING UP THE RWG100

At switch-on, the unit defaults to **Local mode**. In this mode the output waveforms are enabled and are controlled by the front and rear panel switches.

To **view the waveforms on an oscilloscope**, connect one of the supplied **coaxial leads** between the **Oscilloscope External trigger input** and the **Ref output BNC connector** on the **RWG100** front panel.

Connect the **second coaxial lead** between the **Oscilloscope Channel 1 input** and the **Waveform output BNC connector** on the **RWG100 front panel**.

### 4.2.3 TO VIEW THE WAVEFORMS IN LOCAL MODE ON AN OSCILLOSCOPE

Connect an oscilloscope to the **WG** as described above.

Set the rotary **Waveform select** switch to **position 1** and the **toggle** switch to **range 1-8** (the **UP** position).

Turn the **Output level** control fully clockwise

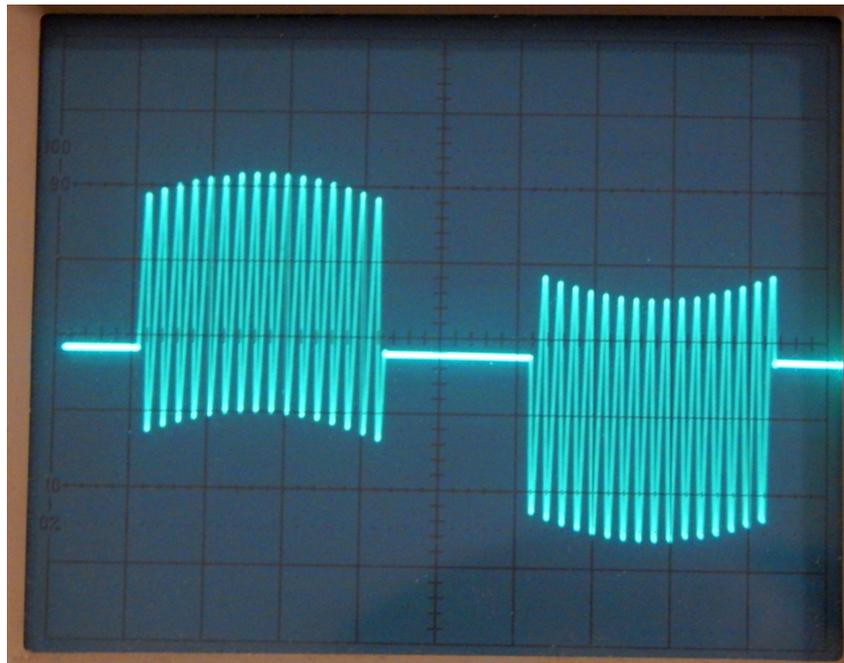
Turn the **output switch** ON

Set the **frequency switch** to **50Hz (UP)**

Set the oscilloscope trigger input to **external**

Set the oscilloscope **vertical gain control** to **2V/division**

Adjust the oscilloscope controls to obtain a stable waveform. A typical waveform is shown below using the RWG100 **reference output** to trigger the oscilloscope in **external triggering** mode.



**Figure 4.2.1. Oscilloscope image of typical output waveform using external trigger**

Notice that the waveform starts approximately in the middle of the first pole. This is a result of the way in which the simulated waveform algorithm has been defined and is also a function of the triggering method.

If the oscilloscope lacks an external trigger input, the **Reference pulse** can be connected to its **channel2 input** and triggered from this channel instead. In this case, the waveforms displayed are shown in the next figure, which shows the relationship between the reference pulse and the flux coil waveform. Note that the **start** of the flux coil waveform (at the centre of one pole) coincides with the rising edge of the **reference pulse**.

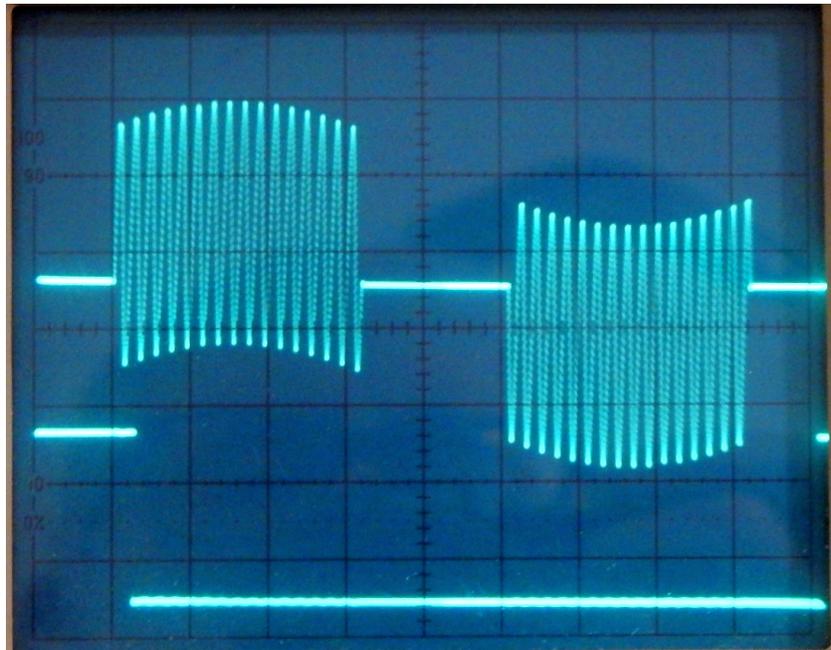


Figure 4.2.2. Oscilloscope images showing Reference pulse (lower trace)

#### 4.3 DETAILS OF PRE-PROGRAMMED WAVEFORMS

The following **simulated flux probe waveforms** have been programmed into the **switch positions 1 to 8**. In all cases, the faulty coil is **number 6** from one pole and the 50Hz (**Power frequency**) component value is 50% of the **flux leakage** component (see section 2.2 for further information).

The **fault percentage** means the nominal percentage of the turns in each coil which are fully-shortened. So for a coil of 10 turns, a 20% fault means that 2 complete turns are shorted.

These **accurate waveforms** can be used to **calibrate flux coil analysis equipment** and also for demonstration purposes.

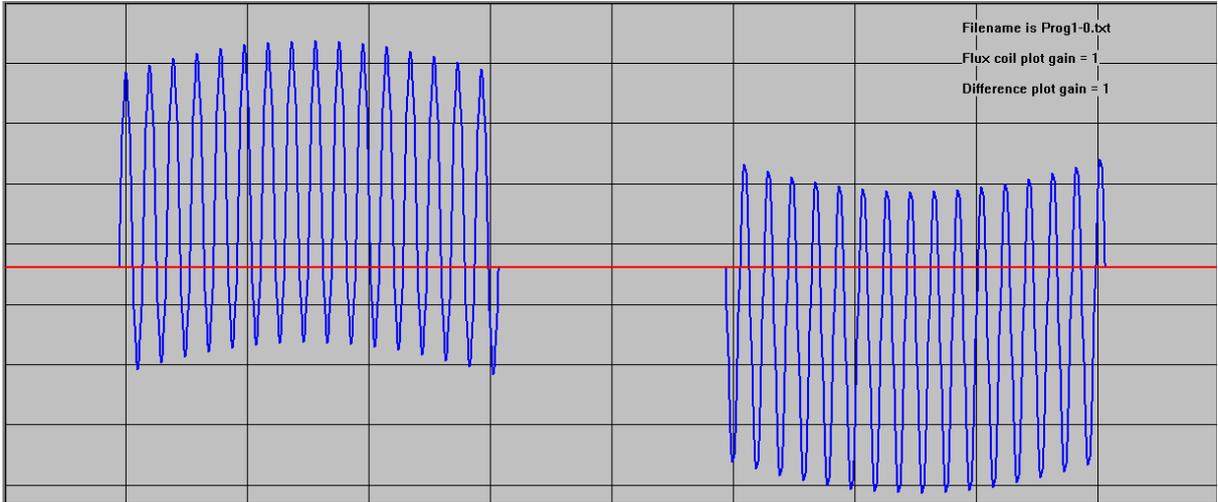
The pre-programmed simulated waveforms are as follows:

Switch position 1.	Fault level %
1	0 (No fault)
2	1
3	2
4	5
5	10
6	20
7	30
8	50

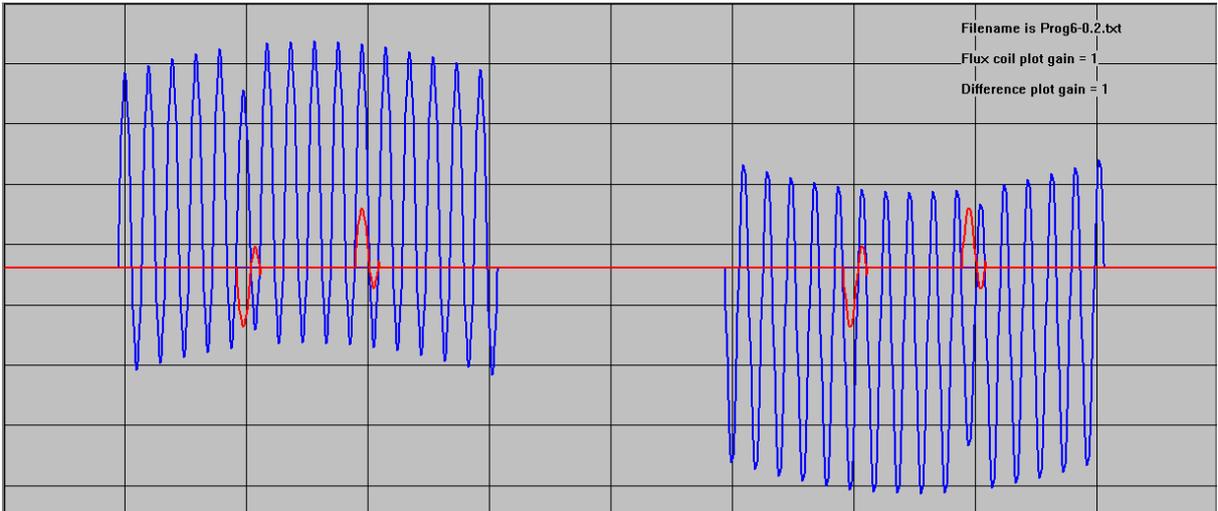
In addition, a number of **measured flux coil waveforms** have been programmed in switch locations 9-11.

The following figures show two of the simulated waveforms plotted using the **Waveplot** program (see section 7 for details).

In each case, the **blue plot** is the flux coil waveform data and the **red plot** is the **Difference (Delay and add)** waveform.



**Figure 4.4.1 Plot of simulated wavform file with no fault**



**Figure 4.4.2 Plot of simulated wavform file with 20% fault in coil 6**

Note that for the case shown in figure 4.4.2, the **Difference (red)** waveform shows fault signals at the location of the faulty coil (6th coil from one pole).

Further detailed information about the use of the **Waveplot** program is given later in section 7.

### 4.5 PROGRAMMING NEW WAVEFORMS

Before a new waveform can be programmed into the **RWG100**, a suitable simulated waveform must be generated. This is done using the **Wavegen** program, which generates a waveform data file suitable for programming the **RWG100** using the **Waveprog** program as described in the next **section**.

## 5. SOFTWARE OVERVIEW

The **RWG100** is supplied with a set of custom software for **generating, viewing and programming** waveforms for use in the **RWG100** unit. Software installation details are given in **Section 11**.

The **RWG100** software is accessed by clicking on the **RWG100 icon**  on the **PC desktop**. This opens the **Program selection** window as shown below.



**Figure 5.1 RWG100 software selection window**

The buttons (**single click only needed**) select the following programs:

**Generate file:** This runs the program **Wavegen** which generates a simulated flux coil waveform file and plots the waveform file data on the PC screen. This allows the simulated waveform to be viewed, inspected, delayed and nulled. The waveform data can then be saved to a **unique file name**. Full details of the **Wavegen** program are given in **section 6**.

**Plot waveform:** This runs the **Waveplot** program which reads the simulated unique data file and plots it on the PC screen. Full details of the **Waveplot** program are given in **section 7**.

**Program RWG100:** Program **Waveprog** programs a single simulated waveform into a **single switch position** in the **RWG100**. Full details of the **Waveprog** program are given in **section 8**.

The **RWG100 Folder** button opens the main software folder **RWG100** which contains all of the executable program files and also the following **sub-folders**:

**Data files:** Contains all of the **waveform data files**.

**Manuals:** Contains this **Instruction Manual** in pdf format.

**Documents:** Contains a number of relevant technical papers.

The **EXIT button** quits the **Program selection** window.

## 5.1 HOW TO PROGRAM A NEW SIMULATED WAVEFORM INTO THE RWG100

The sequence for programming a new simulated waveform file into the **RWG100** is as follows:

1. Generate a new simulated waveform file and check it (click **Generate file** button to run the **Wavegen** program).
2. Save the new waveform to a **unique data file name** (use **Save file** button within the **Wavegen** program before exiting the program).
3. Program the new waveform into the **RWG100** (click **Program RWG100** button to run the **Waveprog** program).

This process is described in detail in the following sections 6 to 8.

## 6. GENERATING A SIMULATED FLUX PROBE WAVEFORM

### 6.1 OVERVIEW

The **Wavegen** program (**Generate file** button) generates **simulated search coil waveform data** files for **flux probes** with any degree of inter-turn fault at any **slot-pair** position. Before the program can be run, some data which defines the waveform file must first be entered.

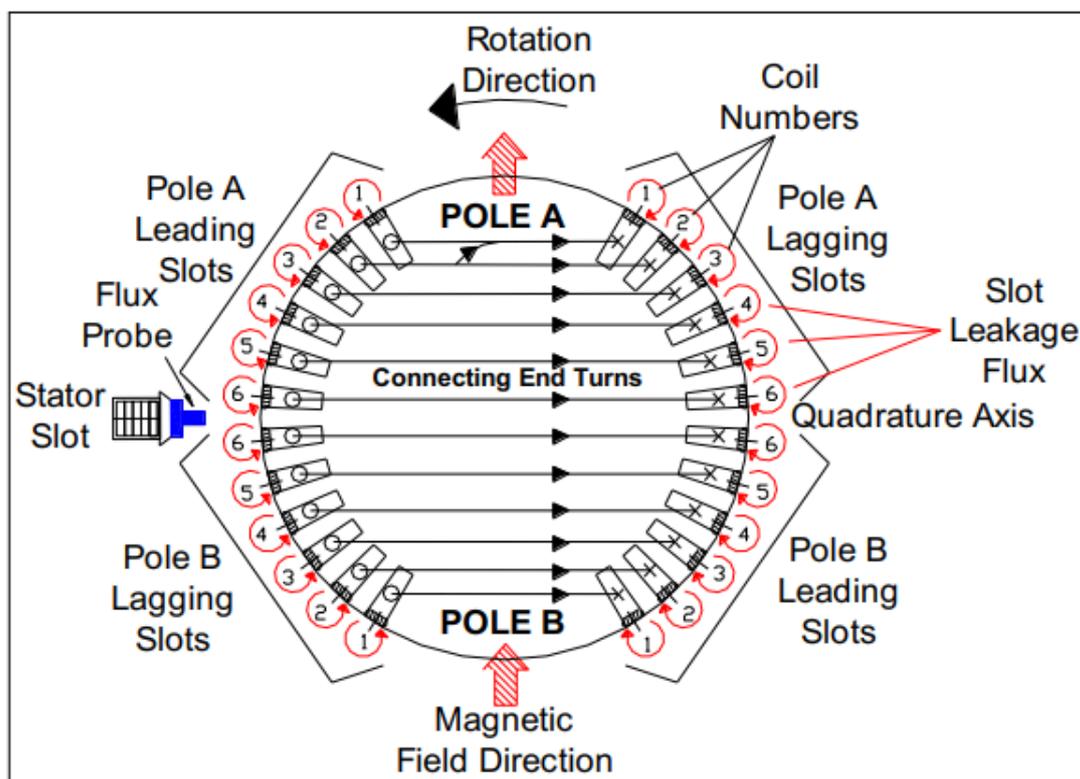


Figure 6.1 Rotor cross section showing slot numbering system \*\*

\*\* From Generatortech paper.

**Figure 6.1** shows a cross-section of a cylindrical rotor with the normal rotor slot and coil numbering system. In this case, each half-winding contains 6 slot-pairs, so there are 6 coils in each half-winding and the slots are numbered from the edge of each pole region. The direction of rotation is anti-clockwise and slots which follow one pole are known as **Lagging slots** and slots which precede the next pole are known as **Leading slots**.

The **Wavegen** software allows the simulated waveforms to be modified by a **50/60Hz power frequency sine wave**. Both the **relative amplitude (mf)** and the **phase angle (Phase)** of the sine wave can be specified.

Sections 6.2 to 6.5 describe how to generate a **waveform file** suitable for programming the **RWG100** unit. Sections 6.6 to 6.10 explain how this file can be viewed and checked before programming it into the **RWG100** unit.



## 6.4 FILE GENERATION PROGRAM Wavegen

To generate a new **simulated flux coil waveform**, click on the **Generate file** button in the **Program selection** window. This runs the **Wavegen** program. This program does not any require any connection to the **RWG100** and can be run on any suitable Windows computer.

The first task is to define the **waveform** parameters. These can either be loaded from a set of **reference values** stored inside the **Wavegen** program, or loaded from a **reference data (.ini) file** which contains the last-used values from the previous run of the program.

When the program is run, a **pop-up window** is displayed which determines how this data is to be entered.

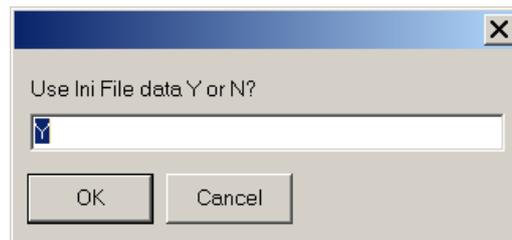


Figure 6.3.1

The default option (**Y**) uses the last-used **parameter values**. Otherwise, the data is loaded from fixed **reference values** stored within the program.

Select the default **Yes (Y)** option by clicking on the **OK** button.

A **Control window** appears displaying the parameter values held within the **reference file**. This file is updated to hold the current values on each occasion when the program is exited.

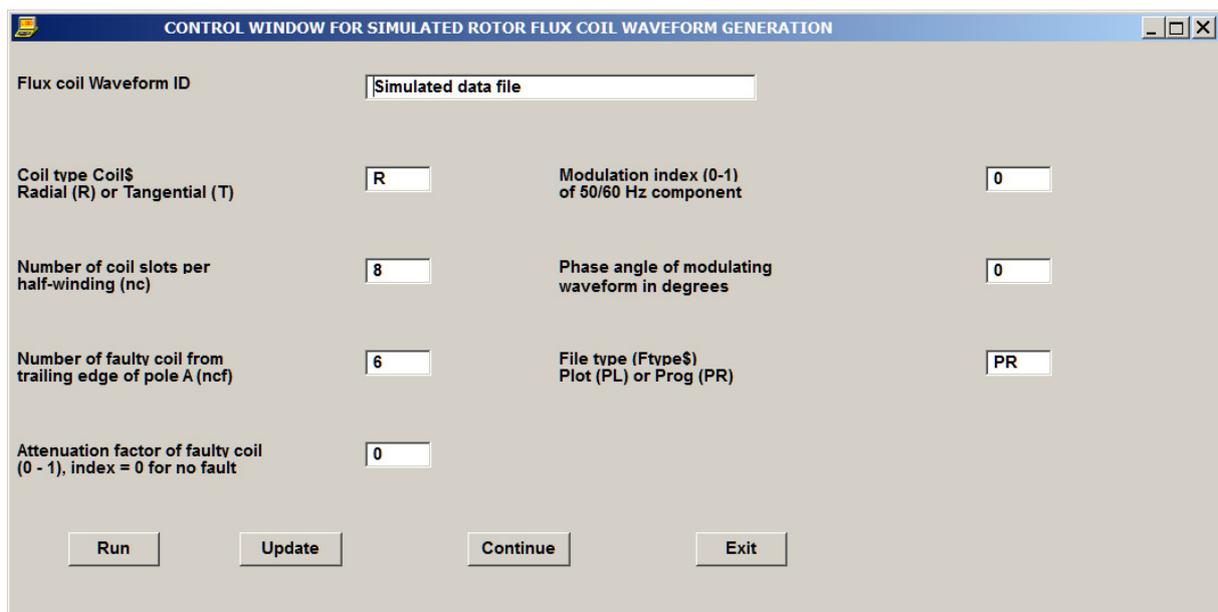
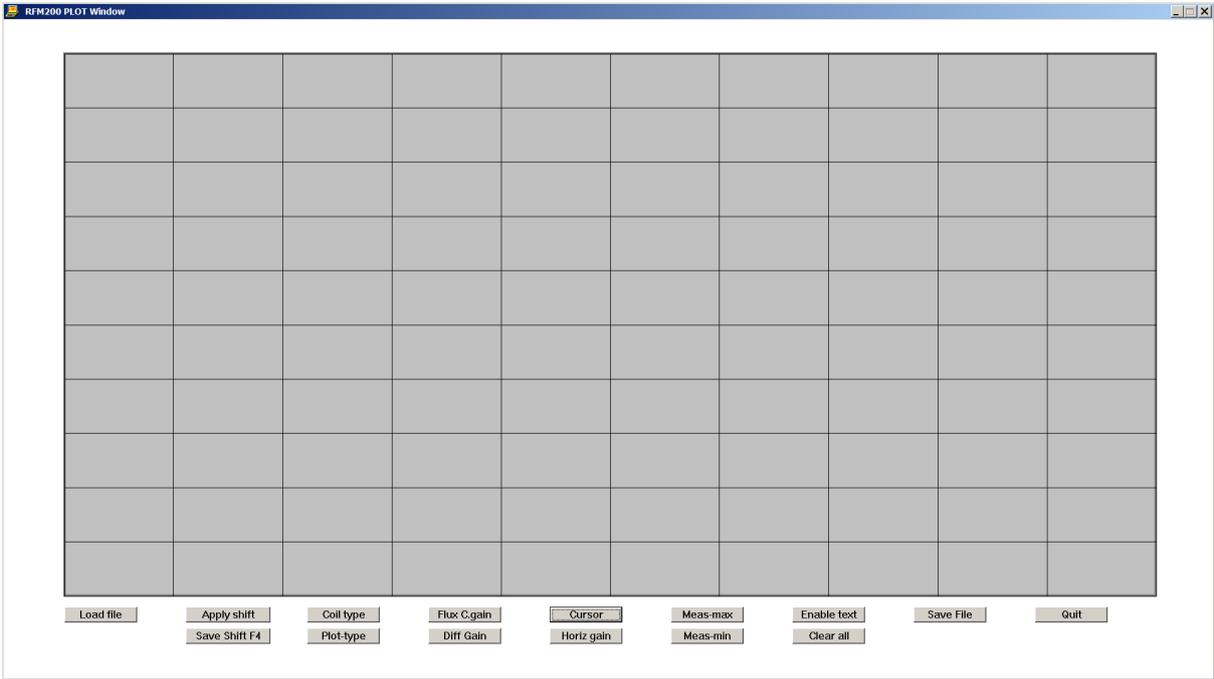


Figure 6.4.1 The Control window containing the input parameters.

The waveform definition input parameters are displayed in the **Control window** shown above. Information about these parameters has already been given in section 6.3.

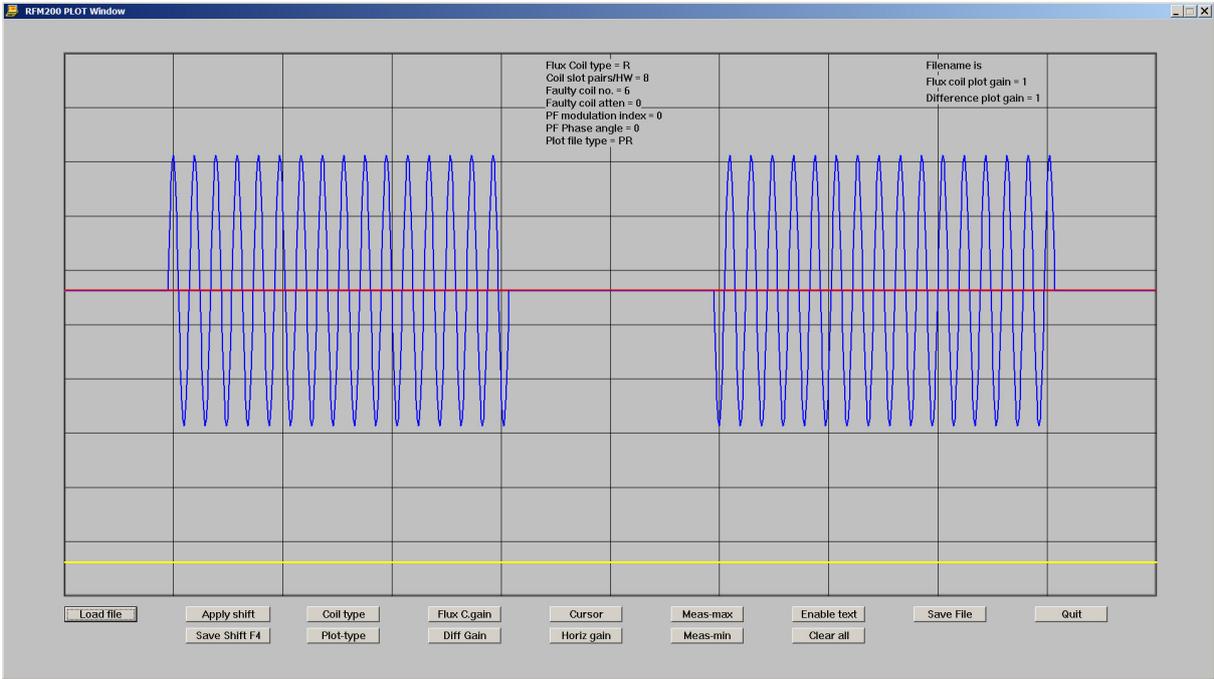
Following any changes, click the **"Update"** button, followed by the **"Continue"** button.

If no changes are needed, simply click on the **"Run"** button to open the **Plot window**.



**Figure 6.4.2. Plot window**

Click on the **Load file** button to plot the waveform, as shown in the next figure.



**Figure 6.4.3. Plot window obtained using parameters shown in figure 6.4.1.**

Figure 6.4.3 shows the waveform produced using the parameters in the previous **Control window**. In this cases, there is no faulty coil and no power frequency component.

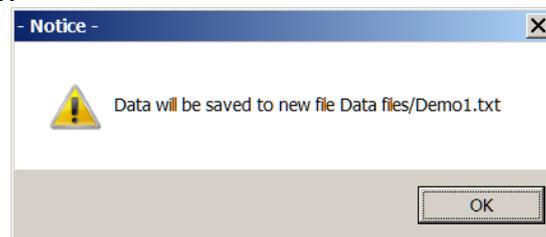
## 6.5 SAVING THE WAVEFORM TO A UNIQUE FILE NAME

To save the waveform to a unique **file name for programming**, click on the **Save file** button which generates a new pop-up window. A unique file name must be entered here with a **.txt file** extension. In this case save the file as **Demo1.txt**.



**Figure 6.5.1 File name window**

When the **OK** button is clicked, a new window appears confirming the file save details as shown below.



**Figure 6.5.2 Confirmation window**

Click on the **OK** button to save the file to the **Data files** folder ready for programming the **RWG100** as described in section 8.

Finally, click on the **EXIT** button to close the **Wavegen** program. The PC reverts to the **Program selection** window.

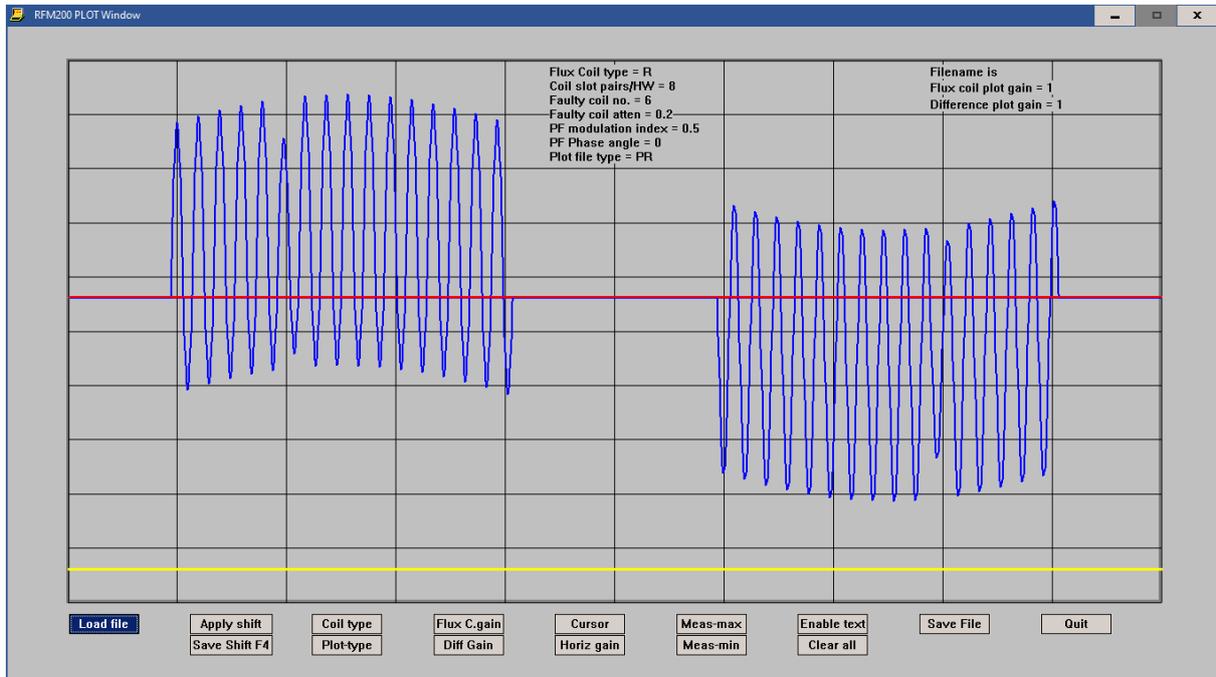
## 6.6 WAVEFORM WITH A SIMULATED FAULTY COIL

Now re-run the **Wavegen** program with new parameters as follows:

Set the **Attenuation index** of coil 6 to **0.2**. This simulates 20% of the turns shorted in **coil 6**.

Set the **Modulation Index** of the 50/60Hz component to **0.5**. This will add a sine wave of amplitude **50%** of the leakage flux amplitude to the waveform.

Now run the program and load the new waveform file as before. The result is shown in figure 6.6.1.



**Figure 6.6.1 Simulated waveform displayed in Plot window**

This is a typical flux probe waveform but with an exaggerated fault amplitude. For most real flux coil waveforms the fault will be difficult to detect simply by observing the flux coil waveform.

Note that the **design parameters** for the simulated waveform are displayed at the top of the **Plot window**. If required, this text can be suppressed as follows:

1. Click the **Enable text** button, enter **N** in the pop-up window and click **OK**.
2. Click the **Load file** button again. The waveform will be re-plotted without the text.

Once the waveform has been displayed it can be saved to a **unique file name** in the **Data files** sub-folder by clicking on the **Save File** button as described next.

## 7. VIEWING AND CHECKING THE SAVED FLUX PROBE WAVEFORMS

After the simulated waveform files have been created and saved, they can be viewed using the **Waveplot** program using the **Plot waveform button** in the **Program select** window..

The **Waveplot** program first requests the waveform file name to be plotted. This file must be in the **\Data files** folder.

Once the file has been selected, click the **OK button** then click the **Load file** button in the **Plot window** which appears. The waveform can then be viewed and manipulated.

In the first case described below, the fault-free **Demo.txt** waveform generated in the previous section is used as an example.

### 7.1 NO FAULT WAVEFORM

For the sake of completeness, we will plot the no fault waveform again before applying some simulated faults.

Click on the **Plot waveform** button in the **Program selection** window. A **File selection** prompt appears.

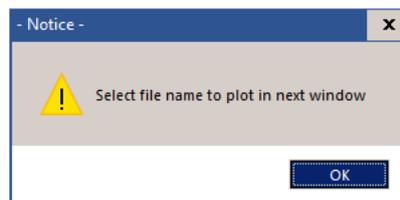


Figure 7.1 File selection prompt window

Click the **OK button** which opens the **Data files** folder.

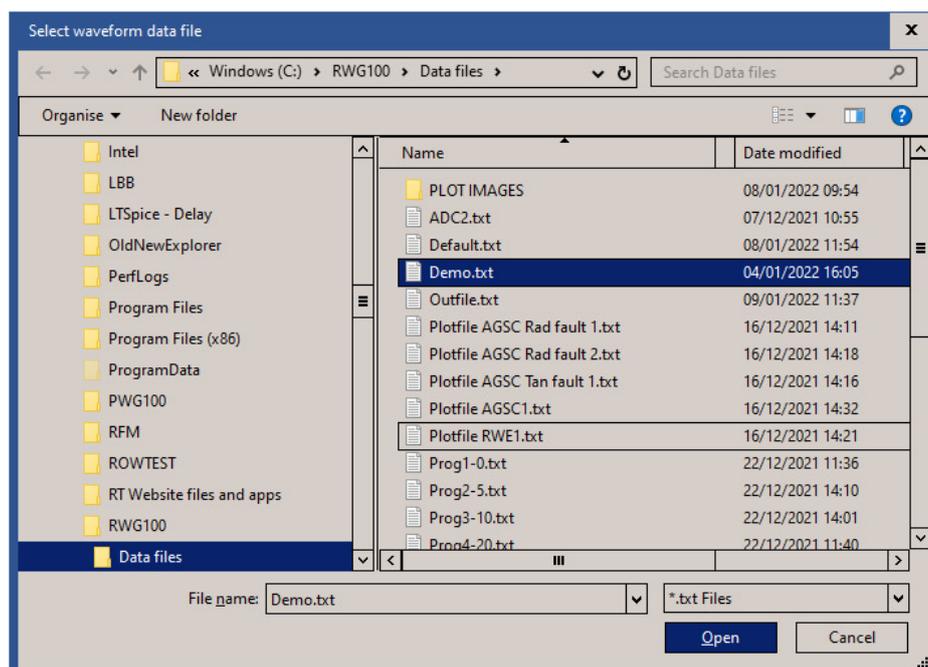
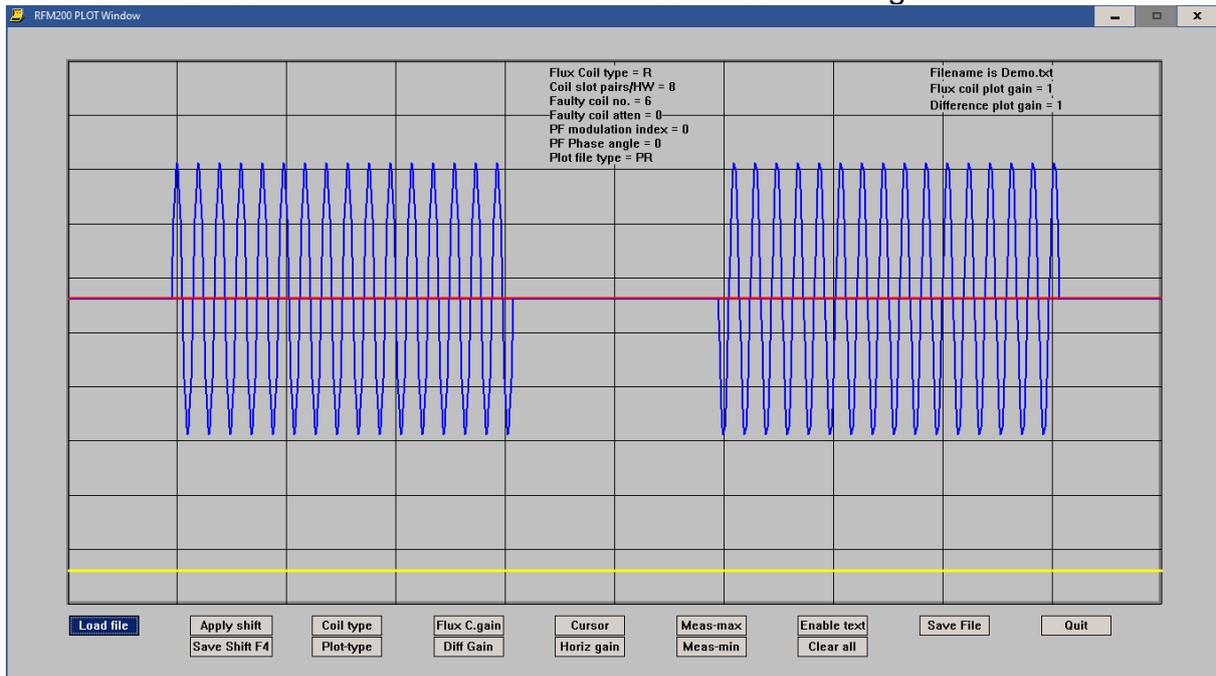


Figure 7.2 Data files window

Select the **Demo.txt** file and open it. This will open the **Plot window**.

Click on the **Load file** button to view the **no-fault waveform** again.

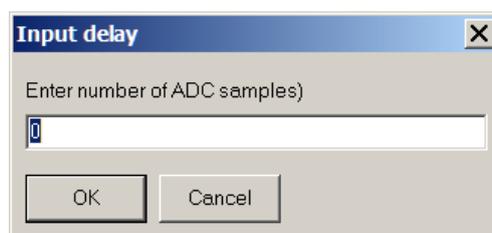


**Figure 7.3 Simulated no fault Waveform**

The waveform shown in figure 7.3 is for a simulated fault-free **Radial** flux probe using the parameters defined in the **Control window** shown in figure 6.4.1. In this case, there is **no power-frequency component**, as would be obtained from a flux coil located close to the rotor surface.

Note that the **second half** of the waveform is the **inverse** of the **first half**.

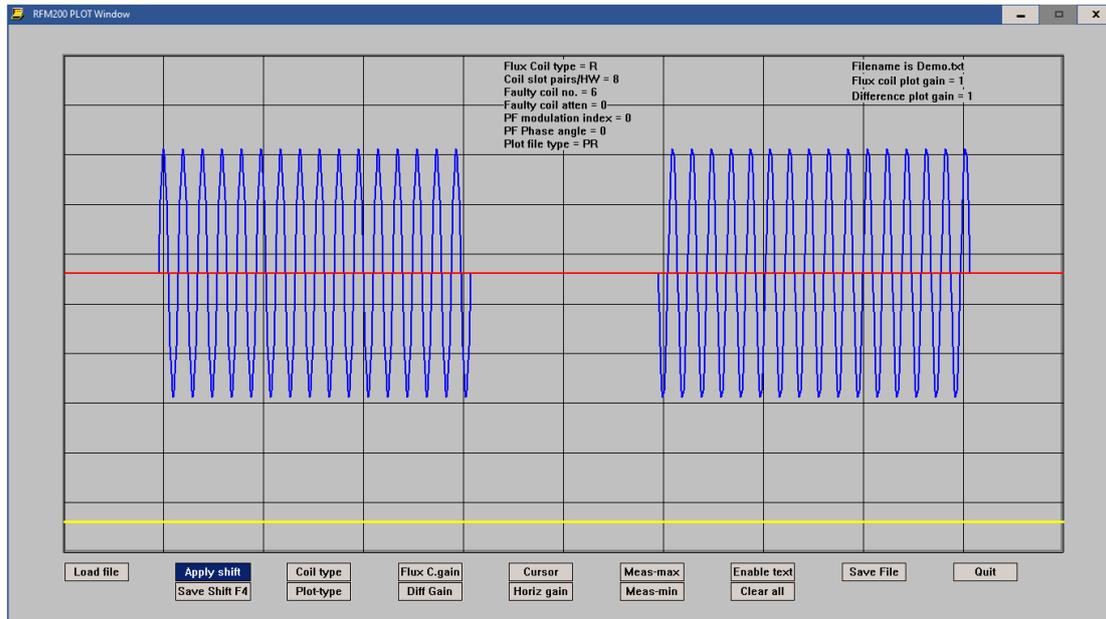
Now click the **Apply shift** button. A small pop-up window appears



**Figure 7.4 Delay and shift pop-up**

Click the **OK (0)** button. The **Difference waveform**, obtained by delaying the whole waveform by exactly one half revolution and adding it to the undelayed waveform is shown in **RED** next.

This is a similar plot to that shown previously.



**Figure 7.5 Plot window displaying simulated waveform for radial search coil with difference waveform (red)**

Figure 7.3 shows the same information as in figure 7.2 but with the addition of the **Difference waveform** shown in red.

As there is no faulty coil in this example, the difference waveform is simply a zero-amplitude horizontal straight line.

Close the **Plot window** by clicking on the **Quit** button.

## 7.2 WAVEFORM WITH A WINDING FAULT

Next re-run the **Wavegen** program and generate a waveform with a 20% fault in coil 6 by changing the **Attenuation factor** to 0.2 as shown below.

CONTROL WINDOW FOR SIMULATED ROTOR FLUX COIL WAVEFORM GENERATION

Flux coil Waveform ID:

Coil type Coil\$  
 Radial (R) or Tangential (T):

Modulation index (0-1)  
 of 50/60 Hz component:

Number of coil slots per  
 half-winding (nc):

Phase angle of modulating  
 waveform in degrees:

Number of faulty coil from  
 trailing edge of pole A (ncf):

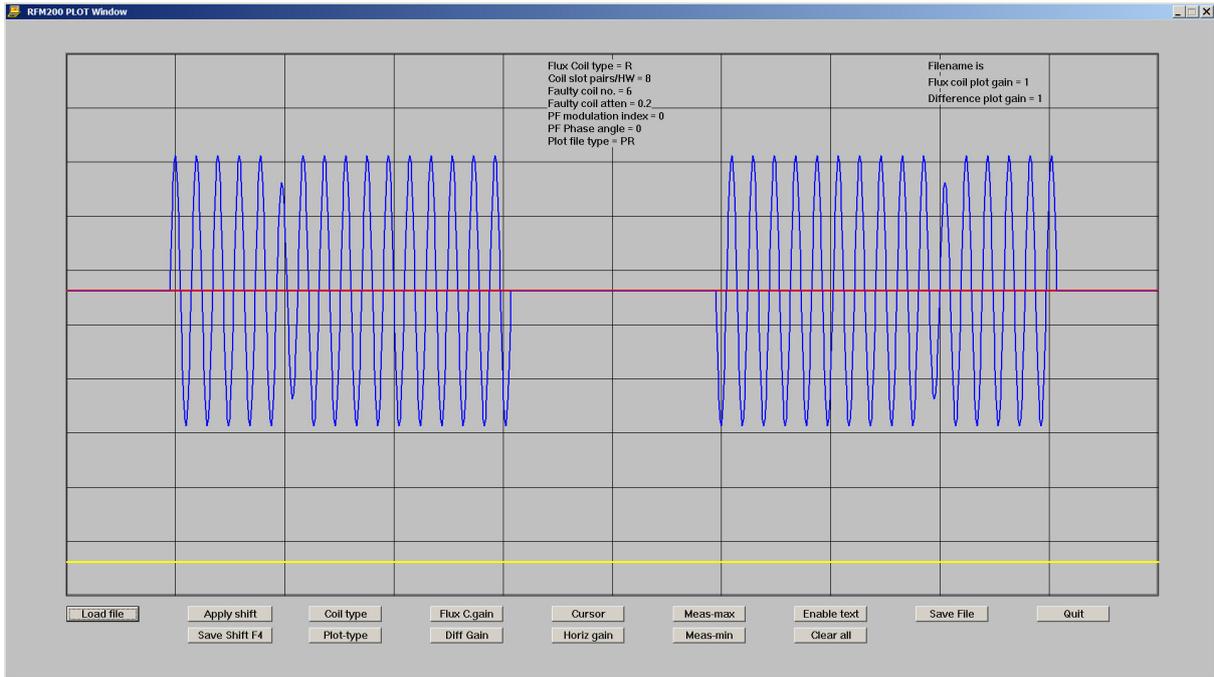
File type (Ftype\$)  
 Plot (PL) or Prog (PR):

Attenuation factor of faulty coil  
 (0 - 1), index = 0 for no fault:

Buttons: Run, Update, Continue, Exit

**Figure 7.6 Control window for a 20% fault in coil 6**

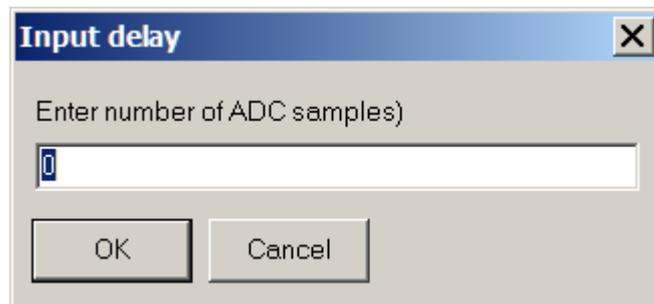
This generates a new waveform as shown below.



**Figure 7.7 Plot window for a 20% fault in coil 6**

Note that the **amplitude** of the waveform corresponding to the **6th coil** from the end of the first polar region has been reduced.

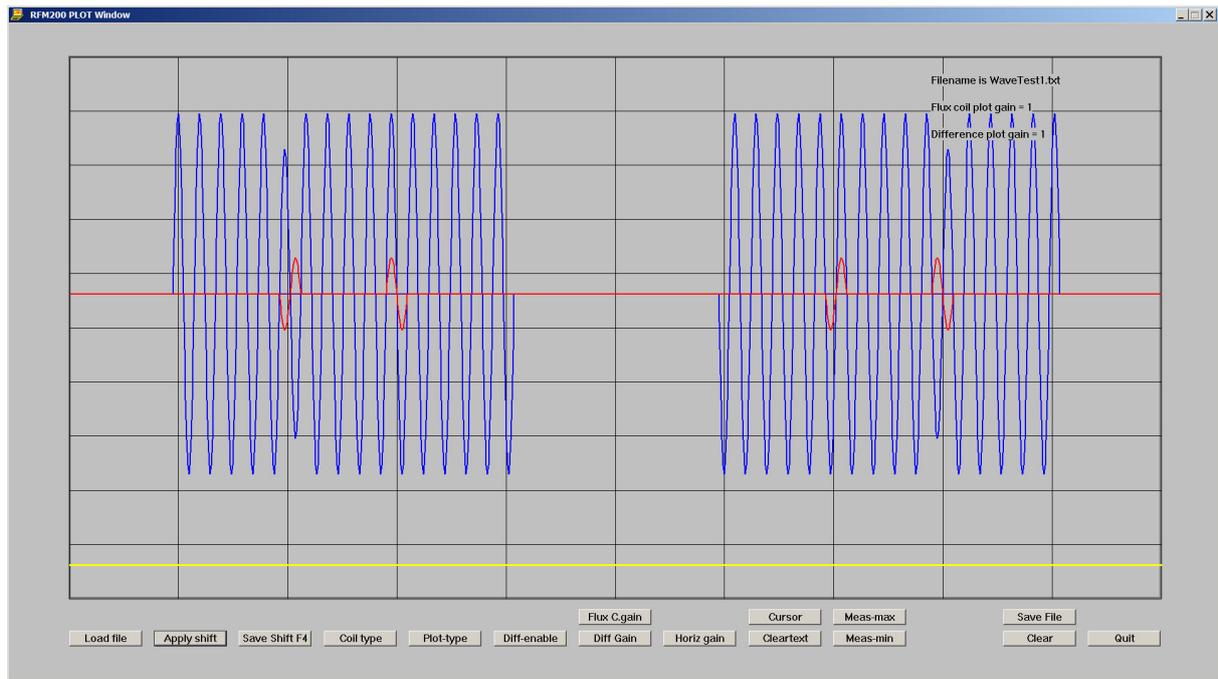
Now click on the **Apply Shift** button. A. new **Input delay** window appears.



**Figure 7.8 Input delay window**

The detailed function of this window will be explained later. For the present, click on the **OK** button.

This generates a new **Difference waveform** shown in **Red** in the next figure.



**Figure 7.9 Addition of Difference waveform**

Note that there are **2 cycles** of the **Difference waveform** in each half-cycle of the flux coil waveform. One cycle is **in-phase** with the main flux coil waveform and the other is **180 degrees out of phase** with the main waveform.

In this case, the magnitude of the applied fault in slot 6 is  $20\% = 0.2 \times 100$ .

As there are 8 coil turns in each slot in this model, this corresponds to 1.6 turns. Realistically, this means 2 turns partially-shortened in coil (slot) 6.

For a real rotor, it is only possible to determine which half-winding contains the faulty pole if there is a **shaft marker** signal available.

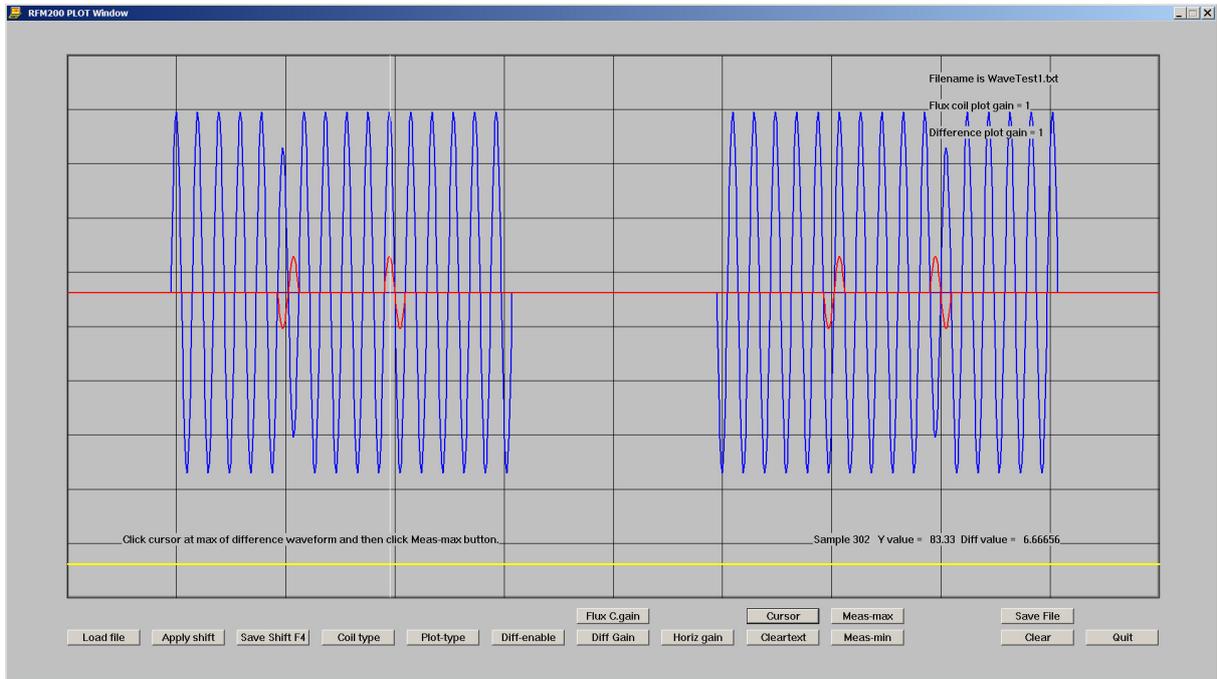
The **RWG100** generates a **reference signal** which simulates a **shaft marker pulse** and details of this are given later.

### 7.3 MEASURING FAULT LEVELS

For **simulated waveforms**, the **Plot window** can be used to measure the **fault level** directly as follows:

1. **Generate, Load and Display** a simulated flux probe search coil waveform and the **Difference** waveform as described in section 7.2.

2. Click the **Cursor** button and locate and click the **cursor** on the **maximum** of the **Difference** waveform, where it is in-phase with the **main** waveform as shown in figure 7.10.

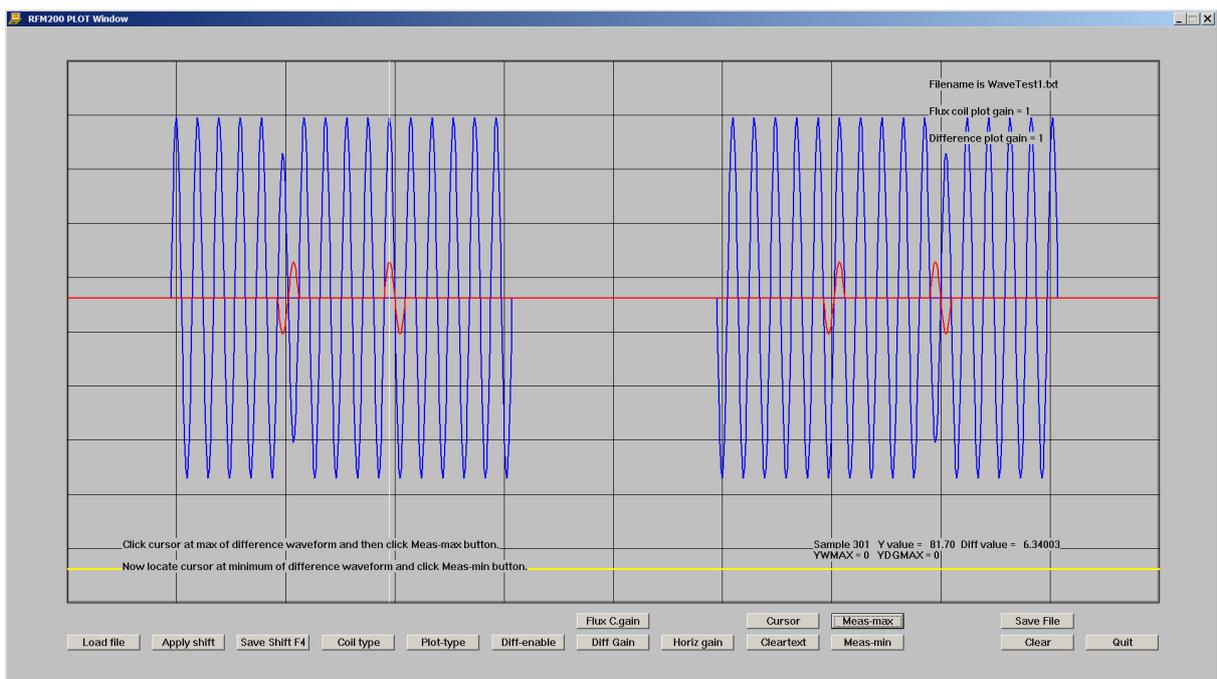


**Figure 7.10 Use of Cursor**

A vertical white line appears at the cursor position and the sample number and its vertical value appears in the **lower right** area of the **Plot** window.

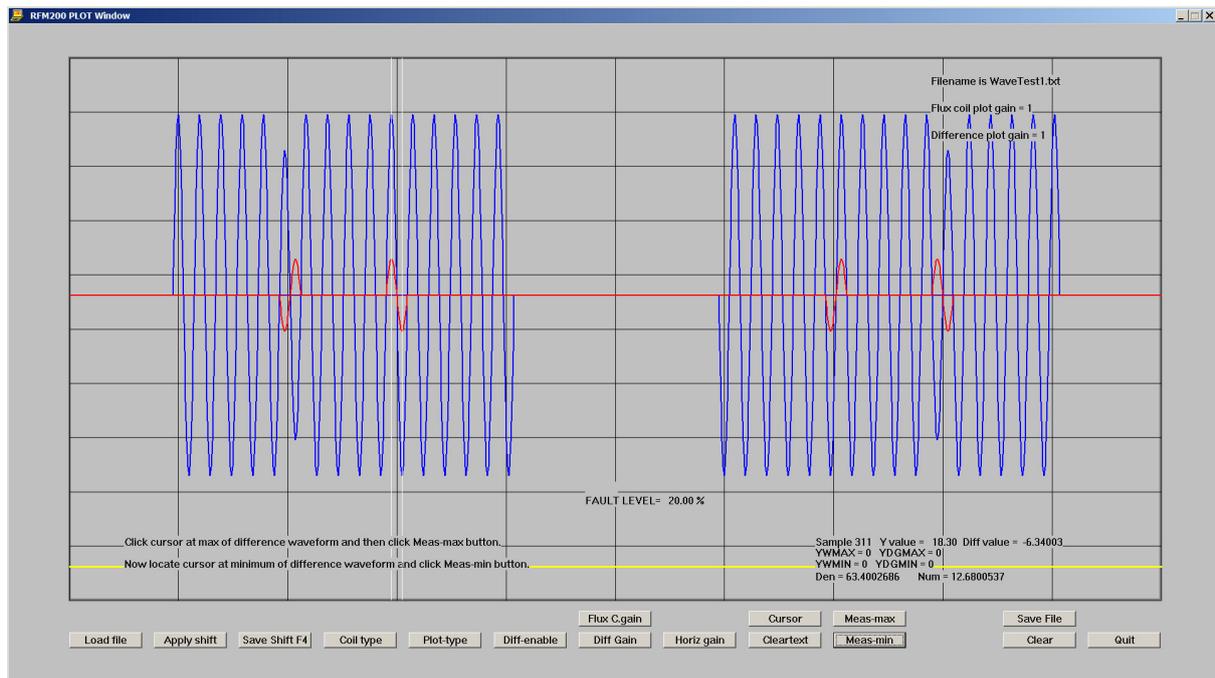
In addition a prompt for the next stage appears at the **lower left area** of the **Plot** window.

Next click on the **Meas Max** button. The relative values of the peak of the **main** waveform and the **Difference** waveform are displayed in the **lower right** area of the **Plot** window and a further prompt for the next measurement stage appears at the **lower left area** of the **Plot** window as shown below.



**Figure 7.11 Measurement of maximum values**

Next locate and click the **cursor** on the **minimum** of the **Difference** waveform where it is **in-phase** with the **main** waveform as shown below and click on the **Meas min** button.



**Figure 7.12 Measurement of minimum values and fault levels**

The **Plot** window is updated with the **minimum** waveform values and then displays the peak-to-peak waveform values and also the **measured fault level** (in this case 20%) derived from these values.

## 7.4 NOTES ON THE USE OF THE PLOT WINDOW BUTTONS

7.4.1. **To clear the screen** to enable further cursor measurements, click on the **Clear** button, then reload the waveform as before.

7.4.2 **To disable the text in the plot window**, click on the **Enable text** button and enter "N" in the pop-up window. Then reload the waveform using the **Load file** button.

7.4.3 **To save the waveform to a new unique file name**, click on the **Save file** button. Full details are given in section 7.7.

7.4.4. **To exit the Plot window**, click on the **Exit** button.

7.4.5. For small fault levels, **the vertical gain** of the **Difference** plot can be increased by clicking on the **Diff Gain** button as described in the next section.

7.4.6. **To Select the search coil type**, enter either **R** (for Radial) or **T** (for Tangential) in the **Coil type** box in the **Plot window**.

7.4.7. The **Plot type** button determines which waveforms are plotted. The options are:

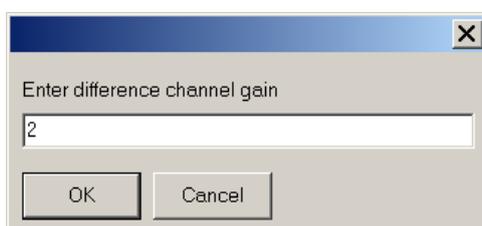
- C** The flux coil waveform only is plotted.
- D** The Difference waveform only is plotted.
- A** (All) Both the C and D waveforms are plotted
- P** This option is not in use at present

Note that the waveform must be reloaded to plot the new selection.

## 7.5 INCREASING THE GAIN OF THE DISPLAYED WAVEFORM

### 7.5.1 INCREASING THE VERTICAL GAIN OF THE DIFFERENCE CHANNEL

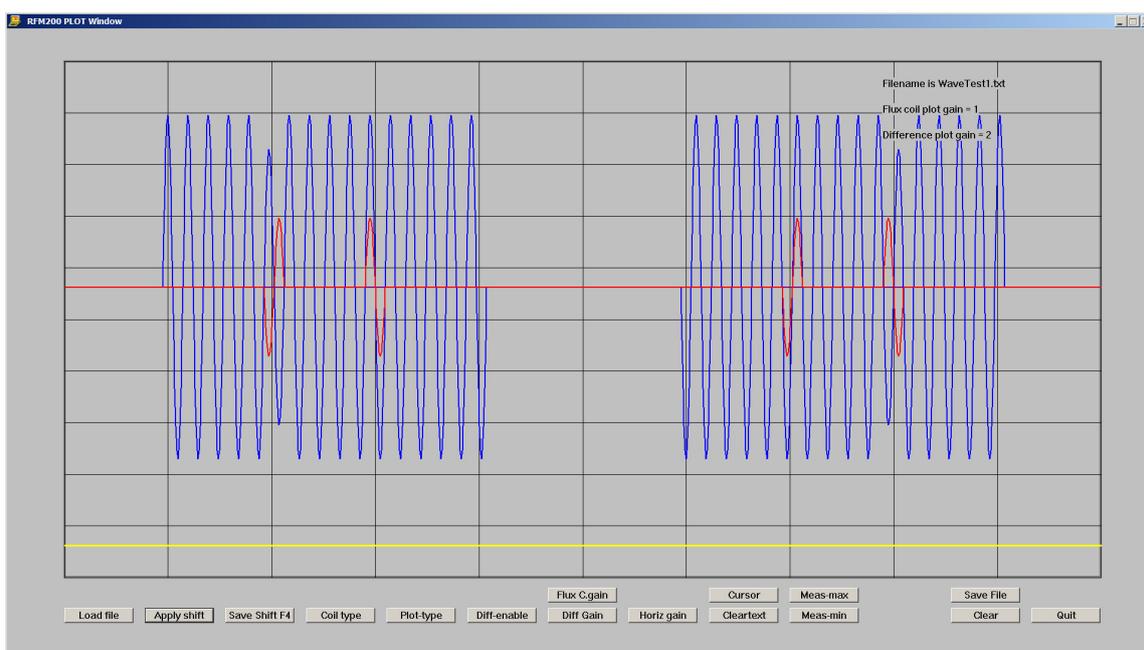
When the **Diff-gain** button is clicked, a pop-up window appears where the new gain figure (in this case 2) can be entered.



**Figure 7.7.1** Increasing the Difference waveform vertical gain

Click **OK** and then click on the **Apply shift** button again to implement the new gain setting. The **difference waveform vertical gain** is increased as shown next. Note that the difference channel gain setting has no effect on the fault level calculation.

The effect of increasing the **Difference channel gain** setting is shown in figure 7.7.2 for a gain setting of **x2**.

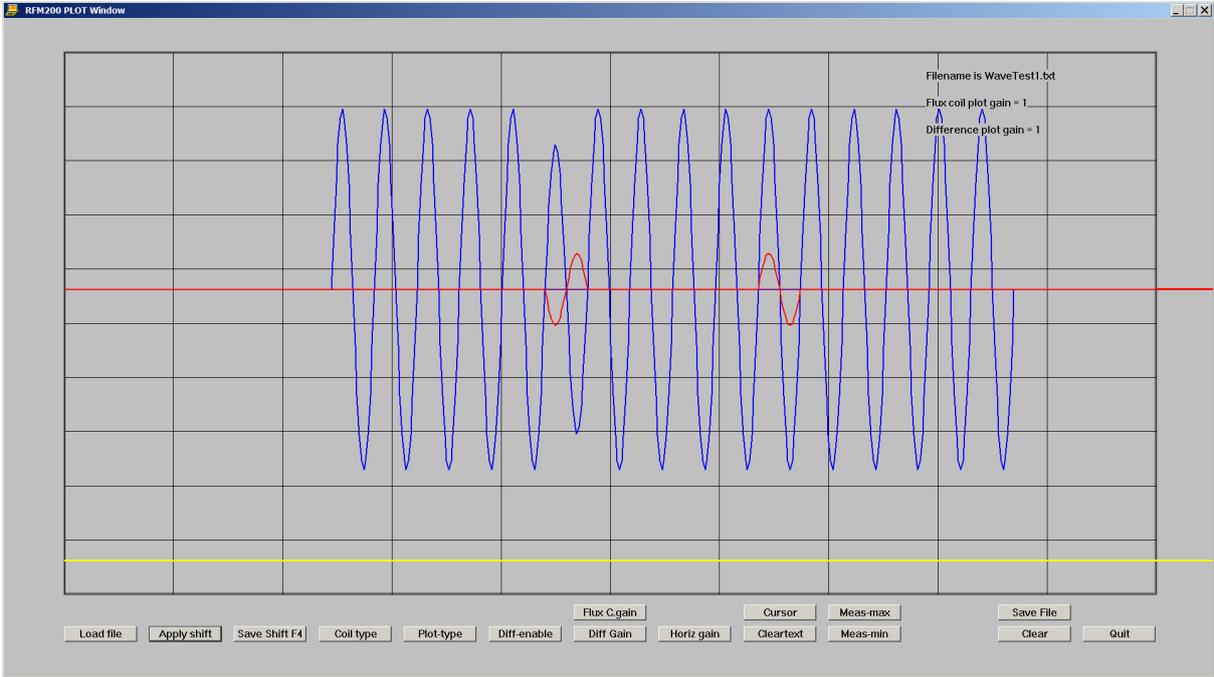


**Figure 7.7.2** Effect of increasing the Difference waveform vertical gain

### 7.5.2 INCREASING THE HORIZONTAL GAIN

Clicking on the **Horiz gain** button allows the horizontal gain of the displayed waveform to be changed and a further pop-up window appears.

Enter a new value (eg 2) and click the OK button.

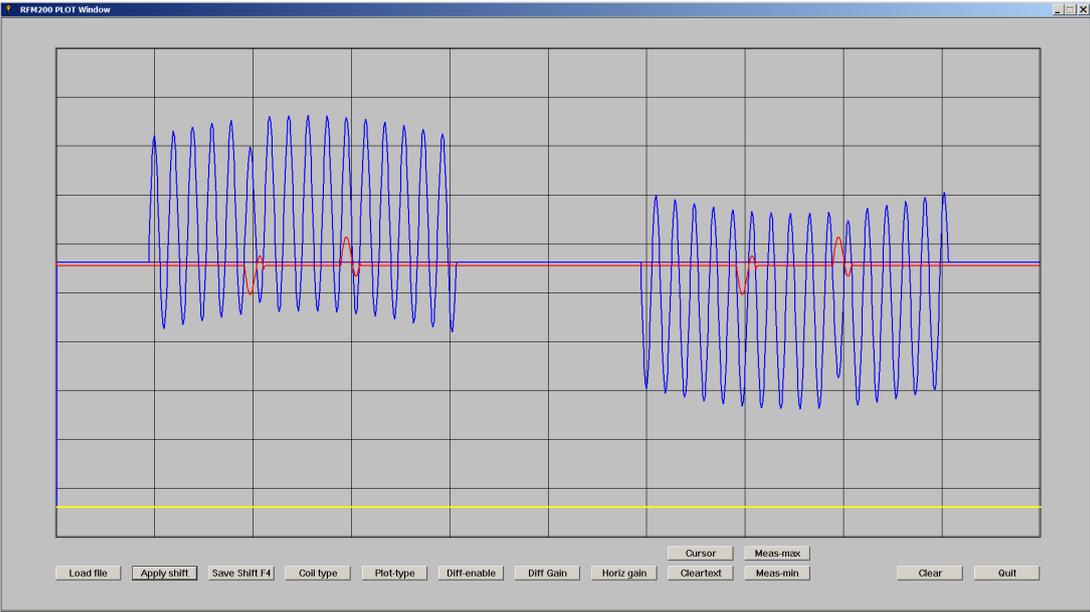


**Figure 7.7.3 Increasing the Horizontal display gain**

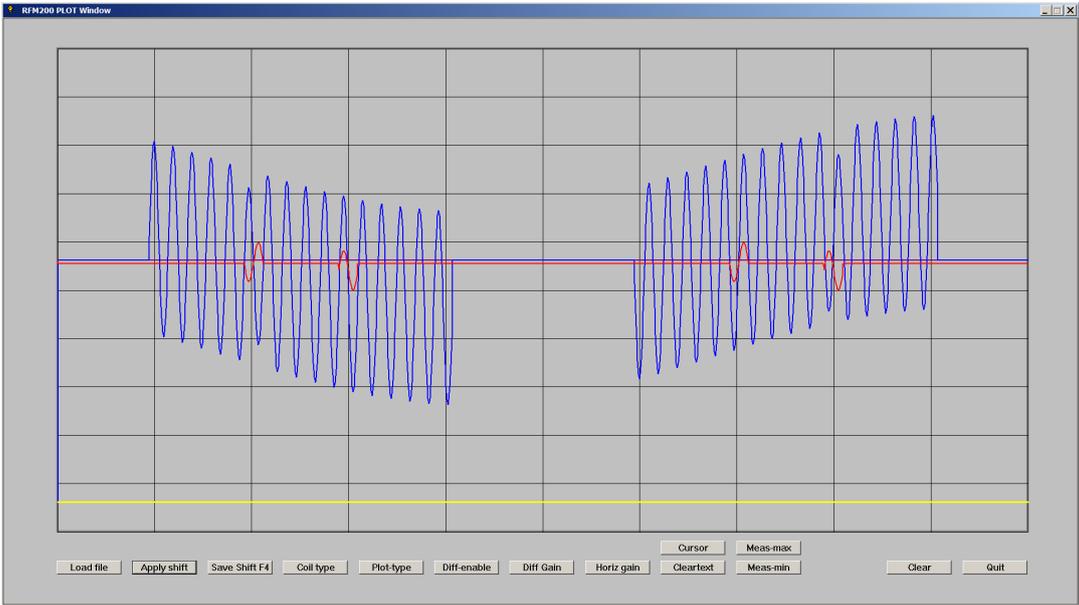
In the above case, the horizontal gain has been increased to x 2. With a **gain of 2**, the effect is to display only the first half-waveform.

### 7.6 EFFECTS OF POWER FREQUENCY AMPLITUDE AND PHASE ANGLE.

The effects on the waveforms of changing the power frequency field component **amplitude** and **phase angle** are shown in the next 2 figures.



**Figure 7.6.1 Radial coil with 20% fault and 50% power frequency component (phase angle = 0)**



**Figure 7.6.2 As above but with phase angle = 90 degrees**

As the relation between the amplitude and phase angle of the two magnetic field components change with load, the shape of the flux coil waveform will also vary.

Note that in all the above examples, the **Difference** waveform remains either **in-phase** or **out-of-phase** with the main search coil waveform, and is independent of the phase angle of the modulating waveform. **This may not be the case for a real search coil waveform.**

## 7.7 SAVING THE DATA FILES.

The waveform generation program **Wavegen** automatically saves the waveform file **Wavetest1.txt**. to the same folder which contains the program file.

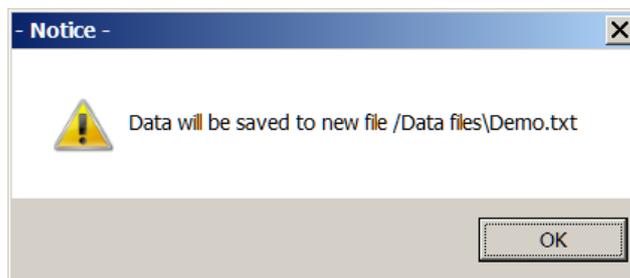
A second file with a **unique file name** can also be generated in the **Data files** sub folder in the **RWG100 folder** by clicking on the **Save File** button in the **Plot window**.

A prompt window appears and users should enter their own file name (including the **.txt** suffix) here instead of the default file name initially displayed. Then click the **OK button**.



**Figure 7.7.1 Unique waveform file name prompt window**

The file name and path to be saved are confirmed in a notice window.



**Figure 7.7.2 Filesave notice window**

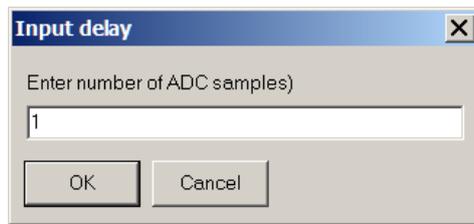
The unique data file name will be saved to the **Data files** sub folder in the **RWG100** folder.

## 7.8 USE OF THE APPLY SHIFT BUTTON

The **apply shift** button automatically nulls the **Difference waveform** for a **simulated waveform file** by delaying a **copy of the the waveform data** by exactly 180 degrees and summing the original and delayed versions of the waveform.

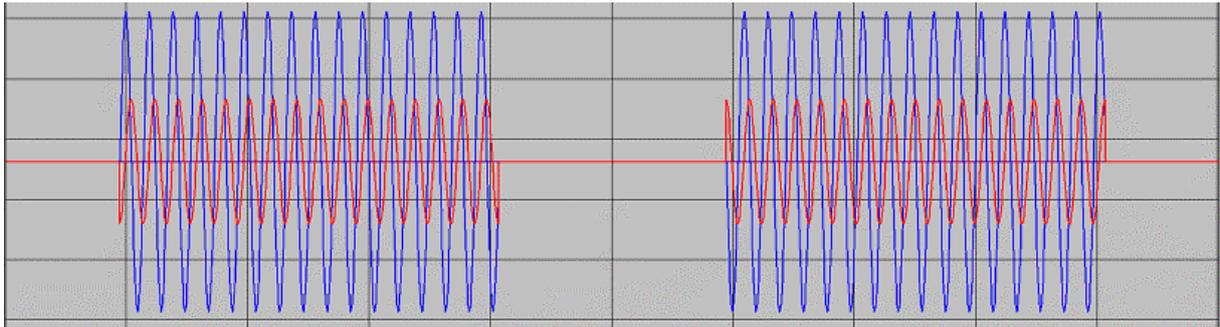
This may not always work for **measured flux coil waveforms** and so the **Apply Shift** button has the option for modifying the amount of delay.

When the **Apply shift** button is clicked, a pop-up window appears and displays a **shift value** (number of ADC samples) = 0 by default. If this parameter is changed to 1 for example, the delay is changed by one ADC sample. As there are 1024 samples in each waveform file, this is a delay change of approximately 0.1%.



**Figure 7.8.1 Apply shift window**

The effect of changing the delay by 1 sample is shown in figure 7.8.2 for the **Demo.txt** waveform.



**Figure 7.8.2 Demo.txt waveform plotted with additional delay = 1 sample**

The **Red difference trace** is no longer nulled, showing how sensitive the waveform nulling process is in reality.

It is possible to enter delay values less than 1 and the next figure shows the same waveform data plotted for a delay of 0.1 samples.



**Figure 7.8.3 As figure 7.8. but with a delay of 0.1 samples.**

For **measured waveforms**, the delay parameter should be varied around the zero value to obtain the best null.

## 8. PROGRAMMING A NEW WAVEFORM FILE INTO THE WG

The **Waveprog** software is used to program a single waveform into a switch position which is selected during the programming process.

During the programming process, the **RWG100** becomes set to **Remote** mode and the front panel controls are disabled (apart from the **Power-on** and **output enable** switch). The **RWG100** is set back into **local control mode** following programming.

Before the program is run, the **waveform file** to be programmed must be present in the **Data files** sub-folder. This will normally happen automatically following the use of the **Wavegen** file generation software, provided the file has been **saved to a unique file name**.

### 8.1 OVERVIEW

The **Waveprog** program sets the **RWG100** into the required states and programs a selected waveform file into the **RWG100**.

The programming process requires the **RWG100 unit** to be connected to the **Control PC** using the supplied **USB to RS232 connecting lead** shown below.



**Figure 8.1 USB to RS232 connecting lead.**

However, before this lead can be used it must be installed to the PC as described in the software installation instructions in section 11.2 and the number of the allocated **serial (com) port** noted.

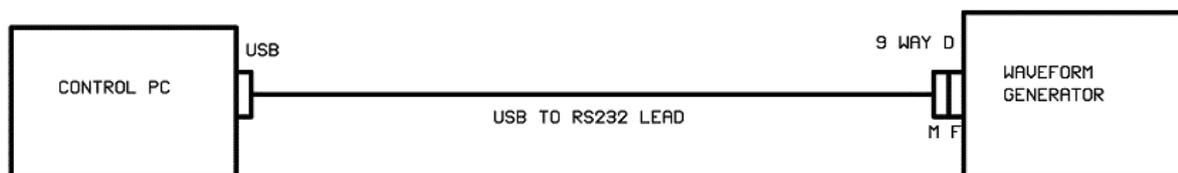
The **Waveprog** software programs a simulated waveform, selected from the **Data files** folder to a single switch position number in the range (1 - 16).

The switch positions 1- 8 (toggle switch **UP**) have been pre-programmed with reference simulated waveform data files and so we suggest that all new files are programmed in the switch positions 9 to 16 (toggle switch **DOWN**).

These **reference files** have also been copied to their own **Reference files** sub-folder in case they become over-written by mistake.

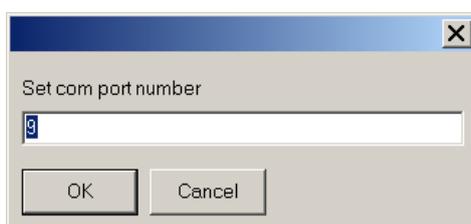
## 8.2 PROGRAMMING DETAILS

Connect the **RWG100** to the **Control PC** using the supplied **USB to RS232** lead as shown below and switch on the **RWG100**.



**Figure 8.1 Connecting the Control PC to the RWG100.**

Click on the **Program waveform** button in the **program selection window**. A window appears requesting the number of the com port in use. The **Com port** address must correspond to the **PC com port number** in current use.



**Figure 8.2 Com port window.**

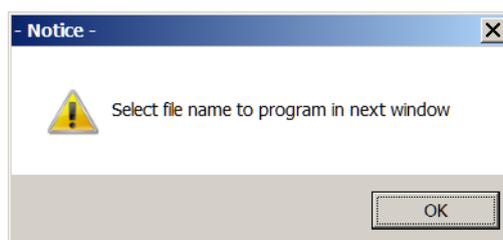
The **PC com port number** can be found by clicking on the **Device Manager icon** in the Windows **Control panel**. For further details, see **section 11.2**.

A new window appears requesting the switch position to be programmed. Enter the required switch position (1-16) and click OK.



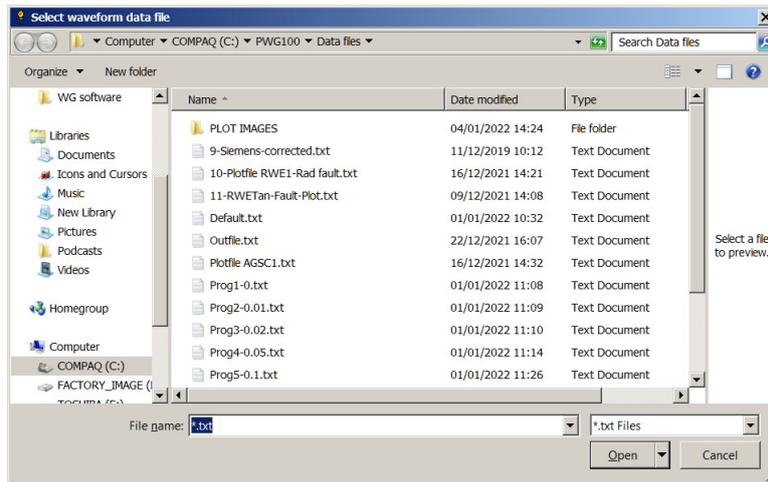
**Figure 8.3 Switch position window.**

A further window opens requesting the file name of the waveform to be programmed. This file must exist in the **WG Programming>Data files** folder.



**Figure 8.4 File name window**

Click **OK** to open the window containing the waveform files in the **Data files** folder.



Select the name of the file to be programmed and **click OK**.

The program now runs and sends the selected waveform data to the **RWG100**. This process takes a few seconds, during which the programming data is displayed on the PC screen .

The waveform will also be displayed on an oscilloscope during programming if one is connected to the **RWG100**.

Note that the actual switch position set on the unit is ignored by the programming software in remote (programming) mode and that the **Waveprog** program must be run for each new switch position/waveform.

## 8.4 DETAILS OF PRE-PROGRAMMED DATA FILES

The **RWG100** has been pre-programmed with simulated waveforms (Modulation Index = 0.5, faulty coil number  $n_{cf} = 6$ ) for switch positions **1 to 8** as follows:

Switch Position	Data file	Details
1	Prog1-0.txt	No fault
2	Prog2-1.txt	1% fault in coil 6
3	Prog3-2.txt	2% fault in coil 6
4	Prog4-5.txt	5% fault in coil 6
5	Prog5-10.txt	10% fault in coil 6
6	Prog6-20.txt	20% fault in coil 6
7	Prog7-30.txt	30% fault in coil 6
8	Prog8-50.txt	50% fault in coil 6

**Some measured real flux probe data files have also been programmed in positions 9 - 12 as follows:**

9	9-SC.txt
10	10-RR.txt
11	11-RT.txt

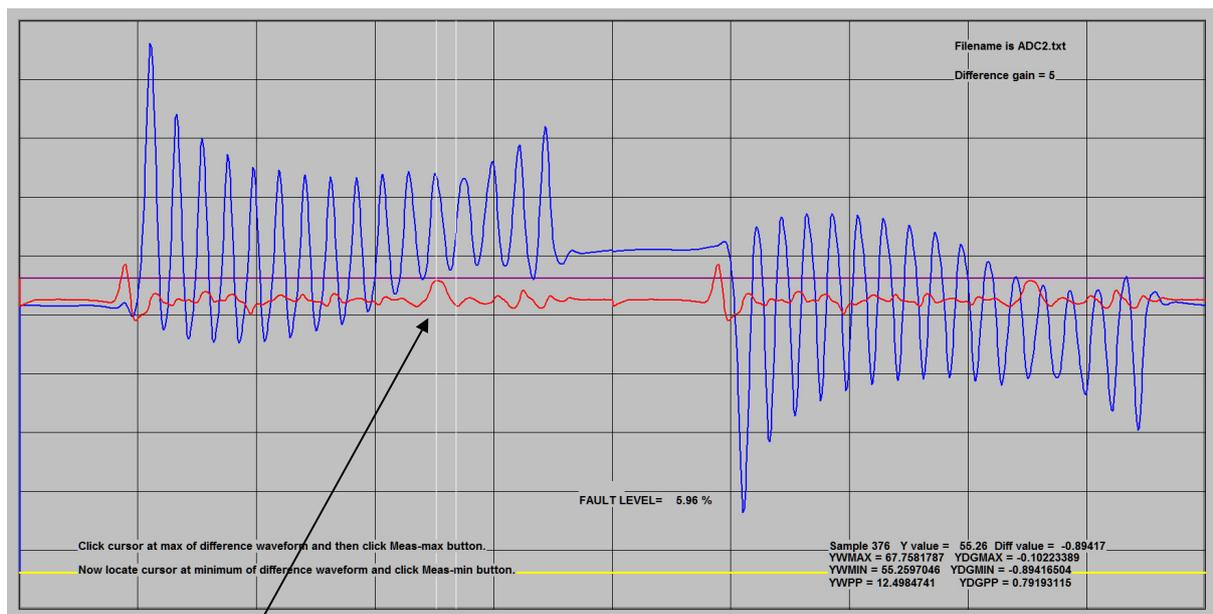
## 9. SOME COMMENTS ON REAL FLUX PROBE DATA.

### 9.1 MEASURED WAVEFORMS

Unlike the plot results for the **simulated** waveforms, the **Difference plots** for real waveforms often do not null perfectly.

In many cases, the **Difference waveform** appears to be largely measurement noise, where the **Difference** waveform is not in phase with the **Main** waveform.

The waveform in the example below is a plot of the **10-RR.txt** sample data file plotted with the **Difference gain** set to **X5**. There is a small but clear peak in the **Difference waveform** which is approximately in-phase with the main waveform as shown below.



Fault ?

Figure 9.1 Measured data

Processing the results as previously, the fault level is shown to be approximately 6%. However, as the **minimum value** of the **Difference** waveform is **not in-phase** with that of the main waveform, this simple processing method gives an error.

An alternative method is to measure the maxima and minima of the main and difference waveforms separately. The range of results is detailed below. These results were obtained by selecting sample measurement points at combinations of the **Main** and **Difference** waveform **maxima** and **minima**.

Sample point maximum	Sample point minimum	Fault level %
Main waveform maximum	Main waveform minimum	2.75
Main waveform maximum	Diff waveform minimum	7.6
Diff waveform maximum	Diff waveform minimum	14.8

On-balance the lowest fault level figure, obtained using the maximum and minimum values of the main waveform is likely to be closest to the correct result.

Note that the small vertical displacement of the difference trace results from the processing algorithm used and has no practical significance.

### 9.2 SOME RESULTS OBTAINED USING IRIS EQUIPMENT

The **RWG100** has been tested using an **IRIS XXX** Flux probe analysis system.

The simulated waveform used was for a Radial flux probe having a 50% power frequency component and a 10% fault in coil 6, as shown in figures 9.2 and 9.3 below.

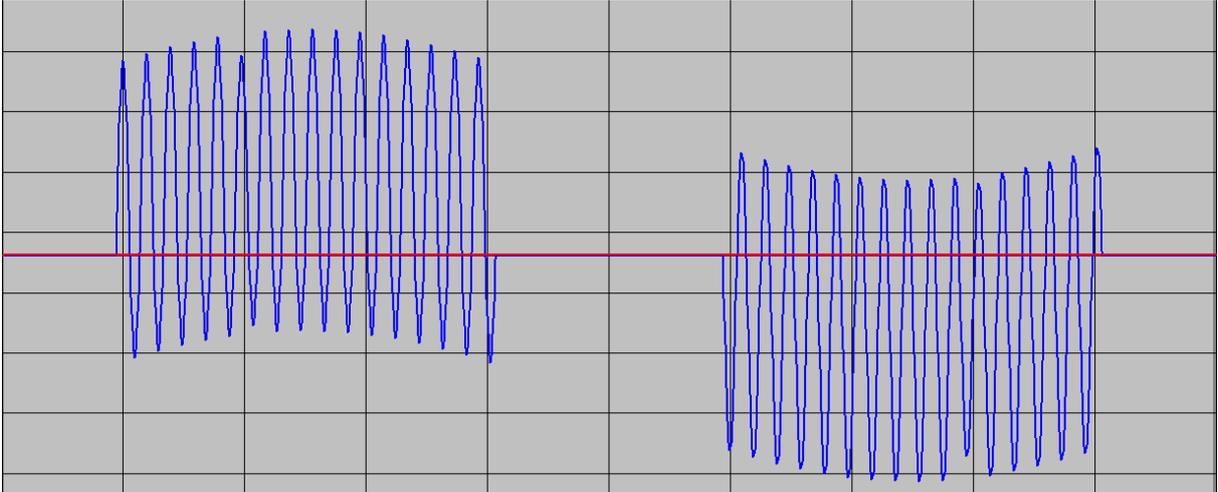


Figure 9.2 RWG100 Simulated test waveform for IRIS test

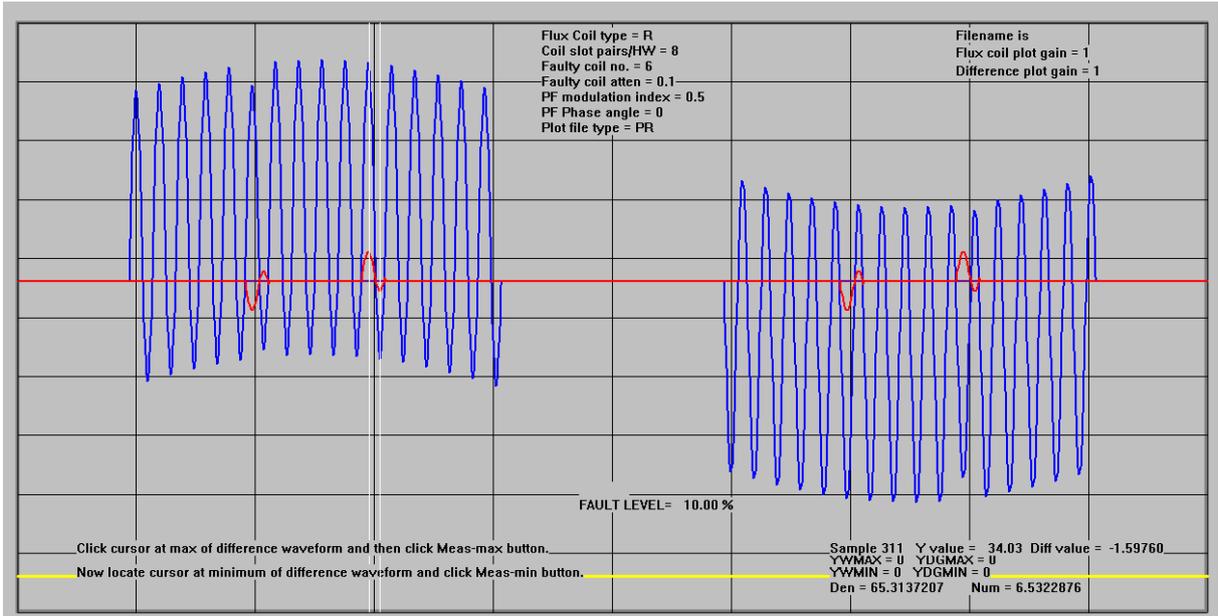


Figure 9.3, As figure 9.2 but with RWG100 analysis data

The next figure shows the results generated by the IRIS RFA-IIR measurement system when the above waveform was used as an input signal. The fault is detected with an amplitude of 10.69%.

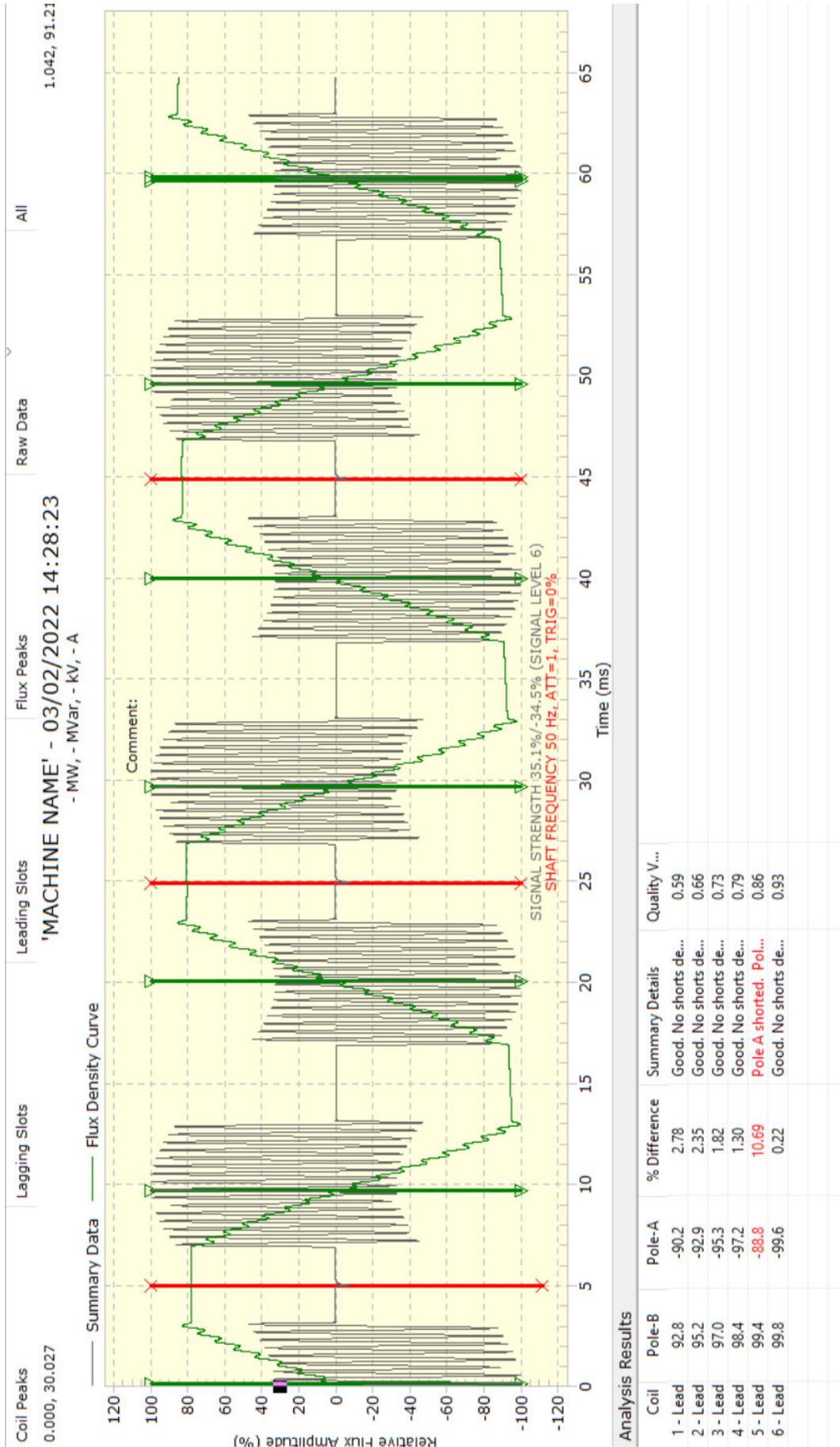


Figure 9.4 IRIS RFA-IIR results for simulated test waveform

## 10. SOFTWARE INSTALLATION ON A NEW WINDOWS PC

### 10.1 RWG100 SOFTWARE

All of the software is contained within a single folder **RWG100** and is supplied on a single CD.

The **RWG100** software is installed as follows:

1. Copy the **RWG** folder from the CD to the C:\ root folder on the PC.
2. Make a shortcut to the file **RWG.exe** and place the shortcut on the **PC desktop**.
3. Right click on the shortcut, **select Properties > Change Icon > Browse** and select the icon file **RWGicon.ico**. Then refresh the desktop to view the new icon.

This completes the **RWG100** software installation.

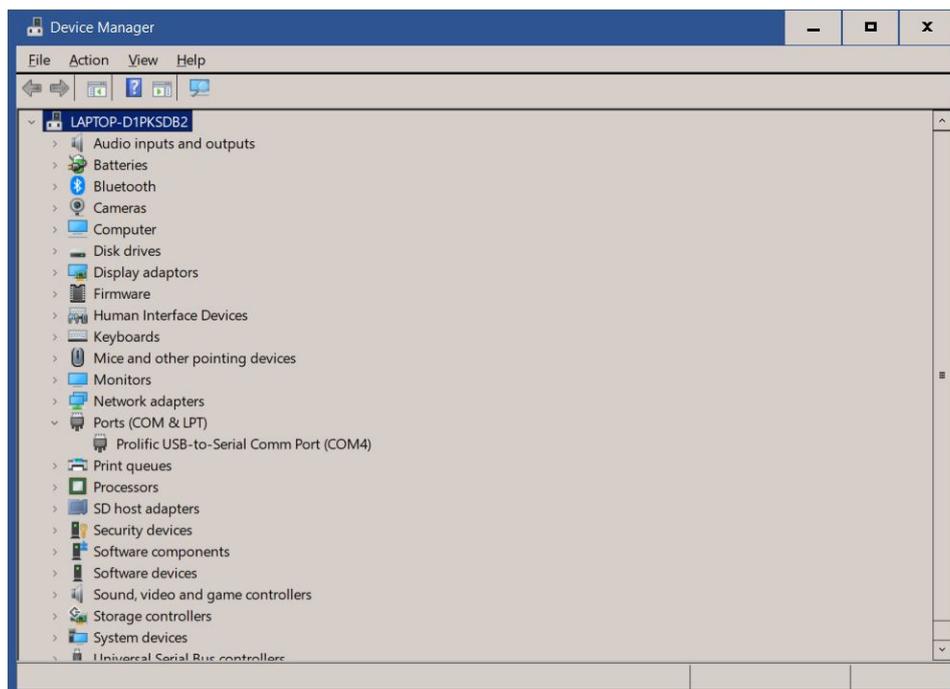
### 10.2 INSTALLING THE USB TO RS232 CONNECTING LEAD

The following procedure will have to be carried out once only for each new PC.

Boot up the PC and connect the USB/RS232 lead to a USB port on the PC.

The PC will try to install the drivers for this device. If these are not available on the PC, use the supplied **Benefei mini-CD** and follow the instructions in the Windows/Driver manual on this CD.

Once the RS232 lead software has been installed, Open the **PC Control Panel** and select **Device Manager**.



**Figure 10.1 The Device Manager window.**

Click on the arrow to the left of the **Ports (COM and LPT)** option. This will generate a new line showing the **Comport** number allocated to the **RS232 lead**.

Make a note of this number (in this case 4) for use with the **RWG100** programming software **Waveprog**.

## 11. RWG100 ROTOR FLUX PROBE CALIBRATOR AND WAVEFORM SIMULATOR SPECIFICATION



**The RWG100 rotor flux probe waveform simulator**

The **Rowtest RWG100** is a custom signal generator which generates a range of waveforms typical of those obtained from the **magnetic flux probes** installed in many **large 2-pole electricity generators**. The signals from these probes are used to check **rotor windings** for shorted turns.

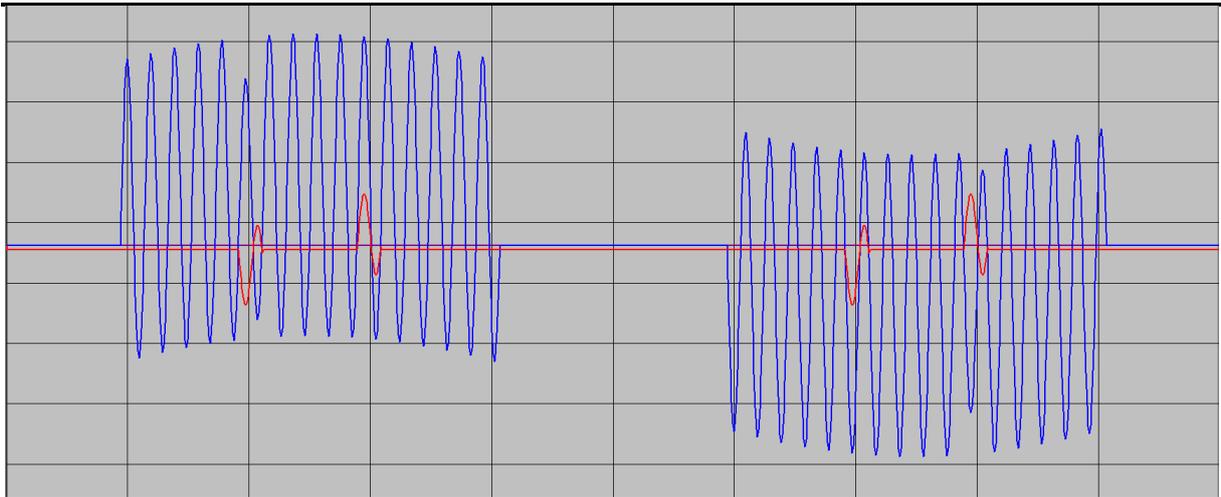
The primary use of the **RWG100** is for **calibrating rotor magnetic flux probe measurement systems**. It does this by generating **accurate simulated flux probe waveforms** with **exact percentage fault levels** which are used as input signals for these measurement systems. This allows the test equipment to be checked for errors before carrying out flux probe tests.

It can also be used to demonstrate the **flux probe measurement technique** for detecting **shorted turns** in **cylindrical rotor windings** and also to provide **accurate waveforms** for testing.

The unit contains **8 pre-programmed search coil waveforms** typical of both **healthy** and **faulty** rotor windings. A **further 8 waveforms** can be programmed into the unit by customers using the **custom software** supplied with the unit. The waveforms can be set to simulate both **50 and 60 Hz** rotation frequencies and can be re-programmed from a PC via a custom USB/RS232 cable (supplied) and custom software.

A synchronised **reference output waveform** which simulates a **rotor shaft pulse** is also generated. Both of these waveforms are available as outputs on the front panel of the unit and can be used to demonstrate or check the accuracy of commercial rotor flux measurement equipment. The reference pulse is particularly useful for triggering an oscilloscope to display a stable waveform.

The supplied software can be used to generate **accurate waveforms for faults of specified magnitudes** in the coils of rotors having between 6 and 10 coils per half-winding for either **Radial** or **Tangential** flux probe coils. The waveforms can be displayed and plotted on a PC and the **delay and sum (subtract)** method can be used to display the **nulled** waveform as shown in the next figure .



### **Simulated radial flux coil waveform for an 8 coil rotor with a 20% short in coil 6**

The **flux probe** waveform is shown in **BLUE** with the nulled waveform in **RED**.

The **RWG100** is supplied with a full set of waveform generating, plotting and programming software together with an external 5V PSU, oscilloscope leads and instruction manuals.

#### **SPECIFICATIONS**

**Power input:** 5V DC via standard USB A connector on rear panel.

**Output 1:** Simulated flux waveform: BNC connector on front panel. 0 - 8V p-p variable.

**Output 2:** Simulated shaft reference pulse: BNC connector on front panel (+5V)

**Waveform selection:** 8-way rotary switch and 2-way toggle switch on front panel

**Simulated Rotation Frequency:** 50 or 60Hz.selectable by toggle switch.

**Program input:** 9-way D connector on rear panel and custom USB/RS232 cable (supplied)

**Software:** Set of waveform generation, plotting and programming software on CD.

**Manuals:** Set of printed software and hardware instruction manuals and on CD

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## **12. APPENDICES**

The following 2 appendices give background information about the construction of large cylindrical generator rotors, winding faults and flux probe testing.

## APPENDIX 1

### A1.1 OPERATING PRINCIPLES OF LARGE ELECTRICAL GENERATORS

A typical (500MW) large electricity generator (alternator) consists of a stationary 3-phase stator winding (the **stator**) which interacts with a rotating magnetic field produced by a rotating electromagnet (the **rotor**). It generates a high-voltage (typically 25kV) alternating current at 50 or 60Hz from insulated conductors located within the laminated stator core. The rotor is normally driven by a steam or gas turbine.

The rotor is located inside the stator, with a radial air-gap of a few cm between them and rotates at high-speed (eg 3000rpm) in normal operation. The rotating magnetic field is produced by a direct current (typically 3000 Amps for a large generator) which flows through through 100-200 turns of partially-insulated copper bars contained within coils located in pairs of radial slots machined into the solid cylindrical steel rotor forging.

The direct current through the rotor winding is usually produced by a DC (or rectified-AC) generator known as the **exciter**, mounted on the rotor shaft. Typical exciter voltages are around 300V DC, so the rotor windings have only relatively low-voltage insulation when compared with the high-voltage (25KV) insulation required for the stator windings.

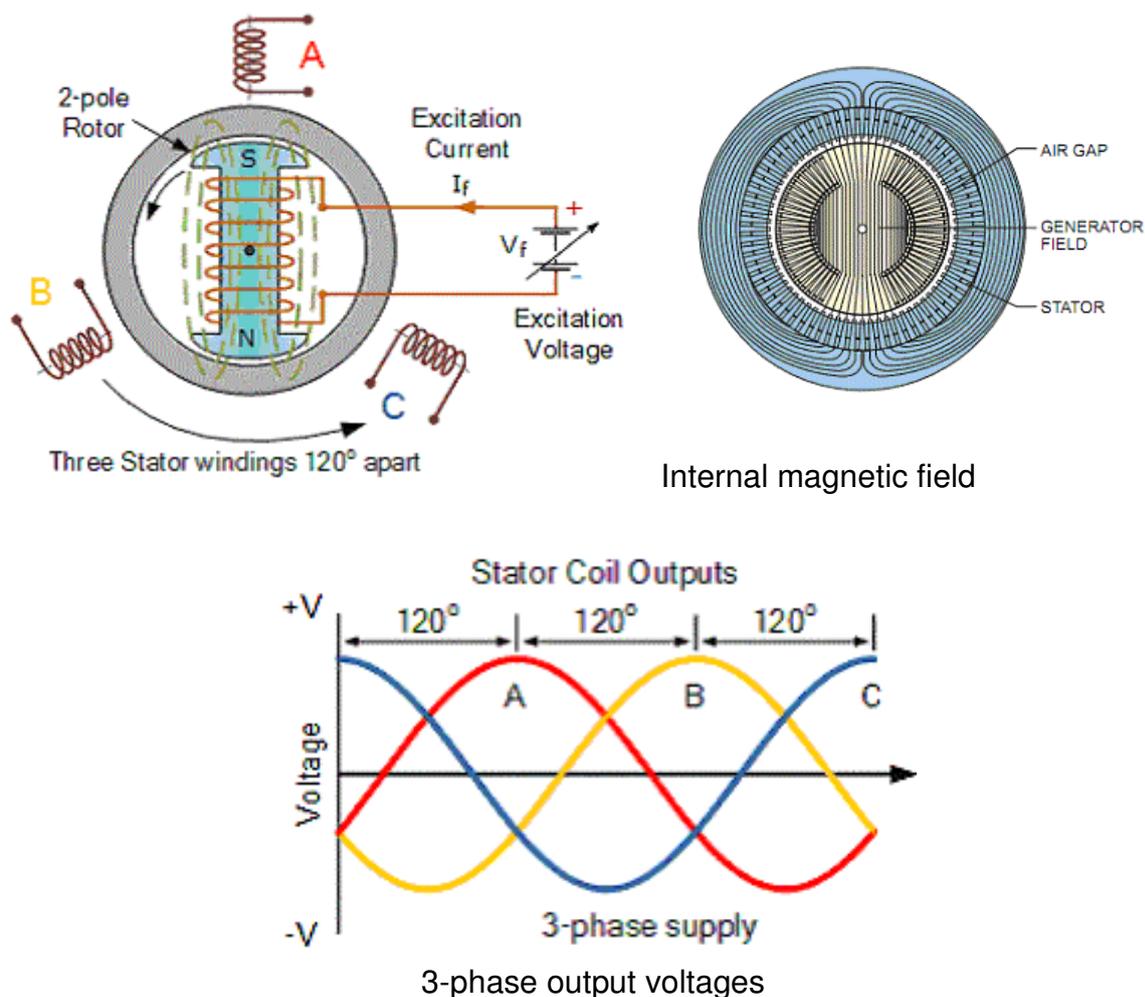


Figure A1.1 Principle of operation of a 2-pole generator.

## A1.2 TYPES OF ROTOR

A rotor can have 2 or more **magnetic poles** and these determine the relationship between the **rotor speed of rotation** and the **supply frequency** generated. For example, the frequency generated by a 2-pole rotor will equal the number of rotations per second, while for a 4-pole rotor, the frequency generated will be 2 x the number of rotations per second etc.

There are a number of different configurations of generator rotors. The 2 main types are cylindrical rotors for use with high-speed turbo generators and lower speed salient pole rotors, which are often used with hydro-electric generators. Examples of these rotor types are shown in the next figures.

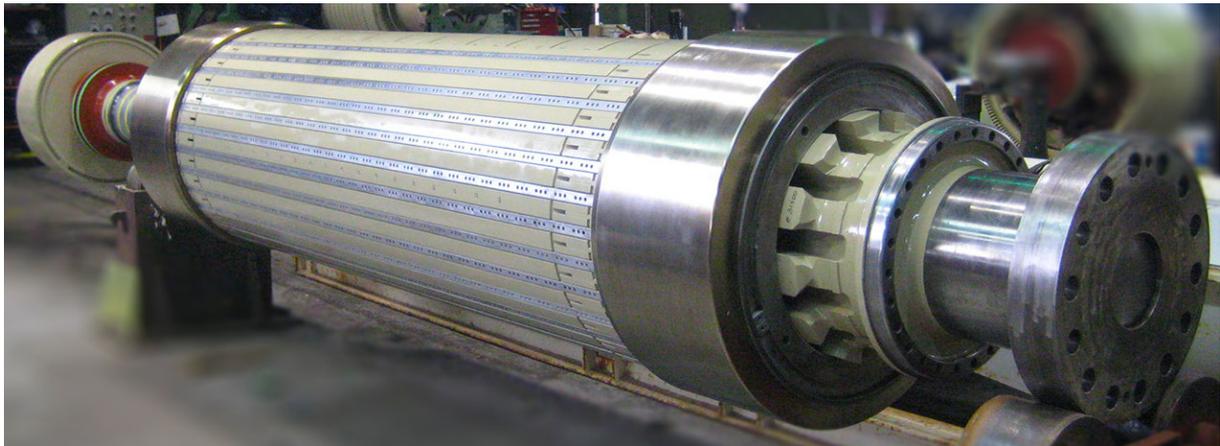


Figure A1.2 Cylindrical turbo-alternator rotor



Figure 1.3 Salient pole rotor type 1

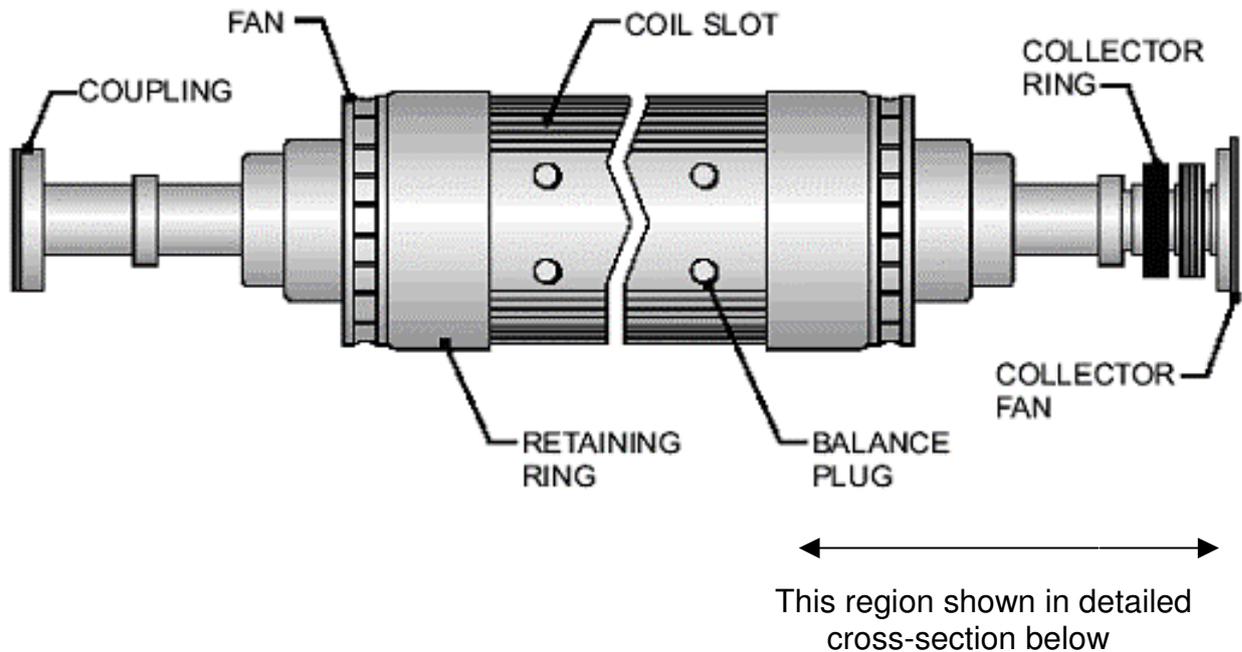
## A1.3 FLUX PROBE TESTS

**Flux probe tests** can only be carried out on **cylindrical rotors**. They cannot be used to test **salient pole** rotors.

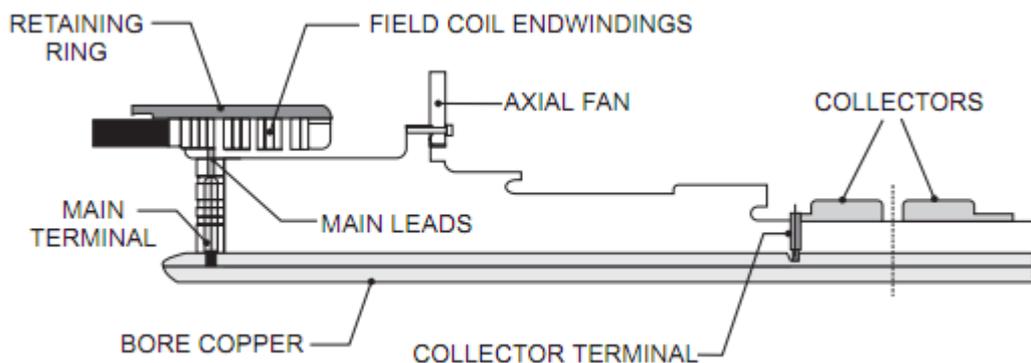
## A2. CYLINDRICAL TURBO GENERATOR GENERATOR ROTORS

### A2.1 OVERVIEW

Details of a typical turbo-generator rotor, together with an image of a typical large turbo-generator rotor with the end-rings removed are shown in the figures below.

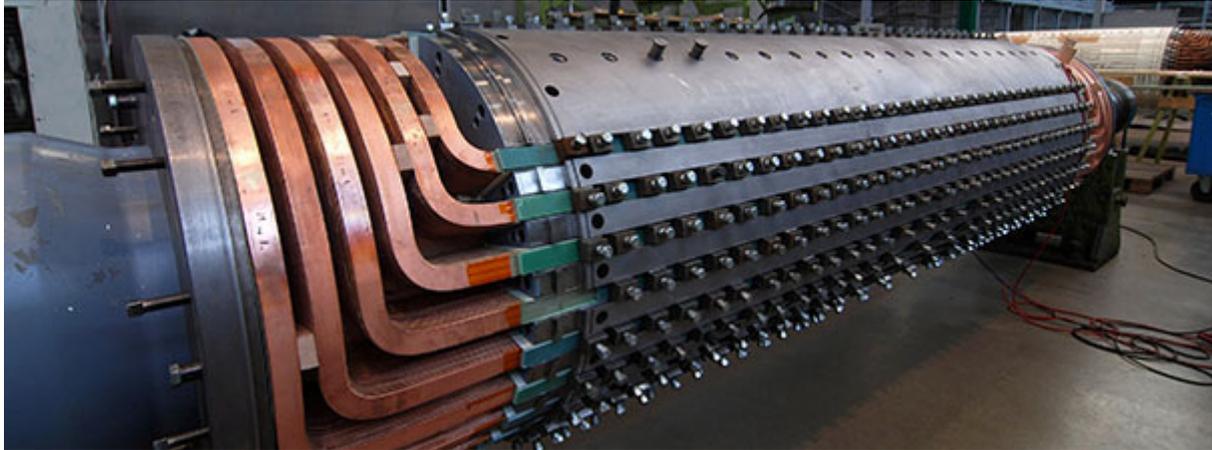


**Figure A2.1 Side view of a typical turbo-generator field rotor**  
(courtesy of GE Power Systems)



**Figure A2.2 Connection between ends of field winding and collector (slip) rings**

The two ends of the rotor winding are connected to the exciter via insulated leads contained within slots or bores in the rotor shaft. In the above example, these upshaft leads are shown connected to conventional slip (collector) rings. In more modern designs, they are connected to rotating rectifier modules mounted on the shaft.

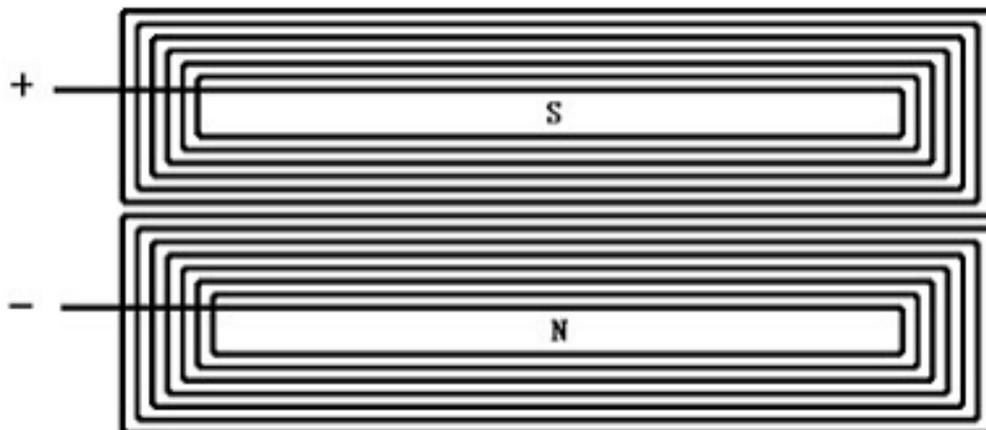


**Figure A2.3 . View of a 2-pole cylindrical generator rotor with both end-rings removed**

Large rotors are typically 16m long, 2m in diameter and weigh 80 tonnes.

The direct current through the rotor winding is usually produced by an exciter, mounted on the rotor shaft. The total magnetic field produced by the rotor winding is directly proportional to the product of the current and the number of turns in the winding.

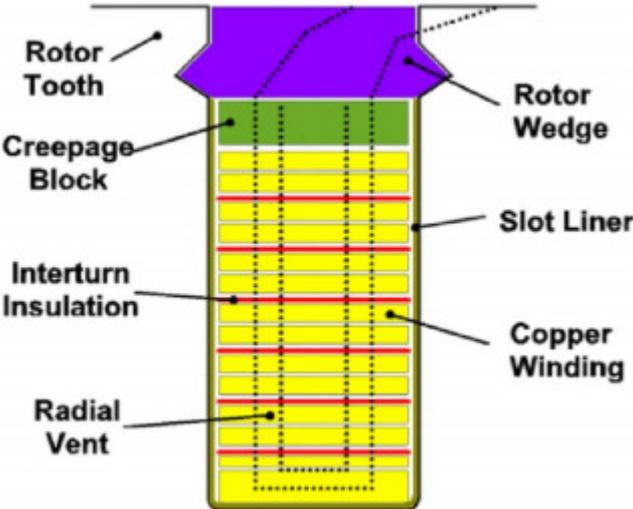
Cylindrical rotor windings normally have either a single or 2 pairs of magnetic poles, and these are known as 2 or 4-pole rotors. An important characteristic of all cylindrical rotor windings is that they are symmetrical when viewed from either slip-ring. A 2-pole rotor contains 2 identical half-windings, one for the North pole and one for the South pole, as shown below. Each half-winding is identical.



**Figure A2.4 Representation of a 2-pole rotor winding showing the identical North and South pole half-windings**

### A2.2 CONSTRUCTION OF CYLINDRICAL ROTOR WINDINGS

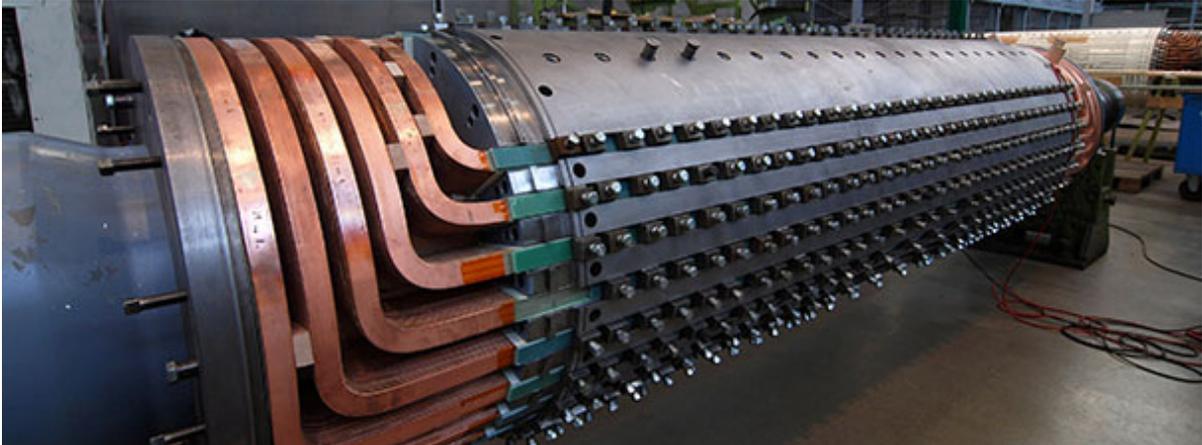
The rotor body is a solid steel forging containing radial slots for the coils which form the rotating electromagnet. The turns of the coils are normally rectangular copper bars insulated with an epoxy material. In a 2-pole rotor, there are typically 8 pairs of slots for each pole of the electromagnet, with each slot containing up to 20 conductor turns. A cross-section of a typical radial slot (in this case, containing 7 turns of insulated copper bar) is shown in figure 2.5.



**Figure A2.5 Cross-sectional view of a radial slot containing the rotor field winding.** (courtesy of GE Power Systems)

The insulation between the turns is typically around 10 to 15 mils (0.3mm) thick and is made from Nomex paper or resin impregnated epoxy glass laminate.

At the ends of the rotor body, the turns pass from the end of one slot to its equivalent slot on the other side of the magnetic pole and are held in place in the end regions by steel end rings. The image below shows the end-winding regions of a rotor with the end-rings removed.



**Figure A2.6 Cylindrical rotor winding with end (collector) rings removed**

One consequence of this form of construction is that the rotor winding approximates to a high-frequency transmission line (similar to a coaxial cable) as the insulated conductors sit within enclosed slots in the metallic rotor forging. This means that if an electrical pulse is applied to one end of the winding, it will travel through the winding to the far end where it will emerge after a finite time delay. The RSO test method uses transmission line measurement techniques, as described later, to identify and locate any faults in the rotor winding.

There is also a second mode of propagation through the winding caused by direct capacitive coupling between the insulated turns. In practice, this is a secondary (minor) mode of propagation, but its effects can complicate the location of rotor winding faults.

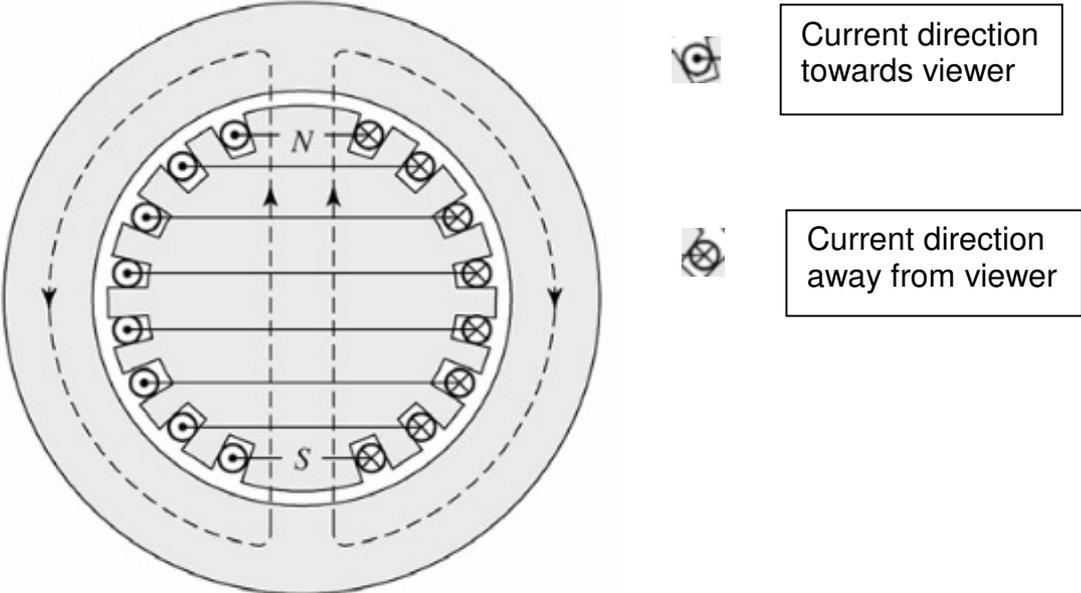
### A2.3 GENERATING THE MAGNETIC FIELD

The Figure below shows a simplified representation of the magnetic field path, magnetic pole locations and conductor slots for a simplified 2-pole cylindrical turbogenerator rotor having a total of 8 coils (4 per half-winding).

A direct current of typically 3000 amps flows through the rotor winding to produce the magnetic field, which is at right-angles to the axis of rotation, with clearly-defined north and south poles.

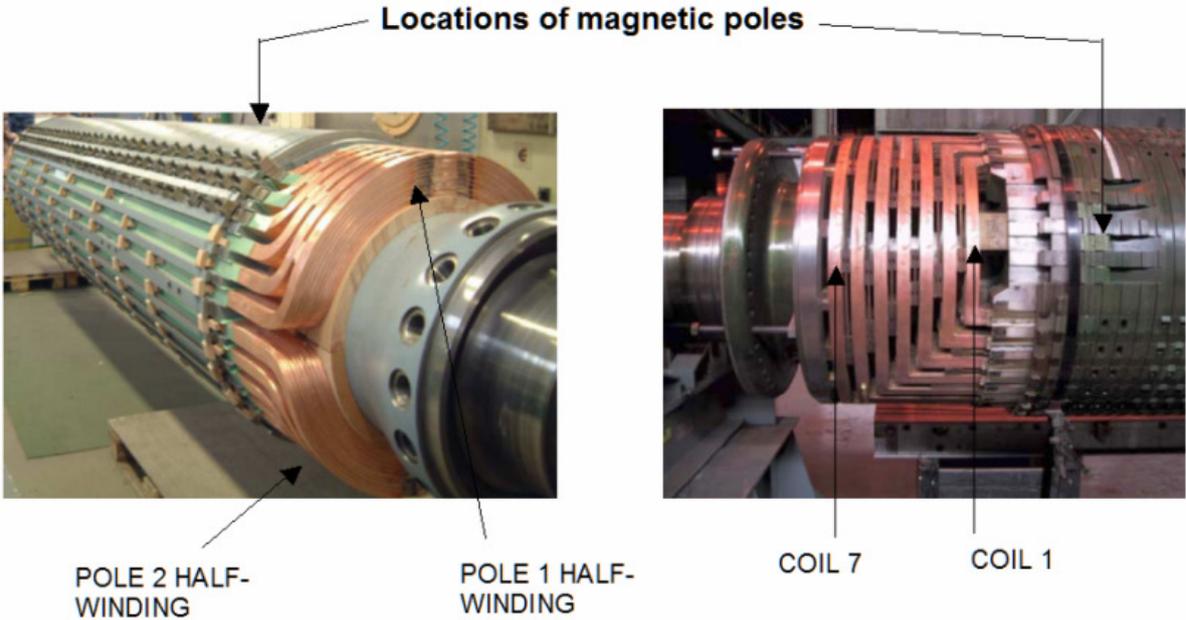
There is a single pair of magnetic poles (1 and 2), which are located along the centre line of each set of coils. Poles 1 and 2 are often referred to as the **north** and **south** poles. The complete rotor magnetic field winding consists of 2 identical half-windings connected in series

The return path for the magnetic field is via the stator laminations as shown below. The magnetic field has radial and tangential components, but no axial component.

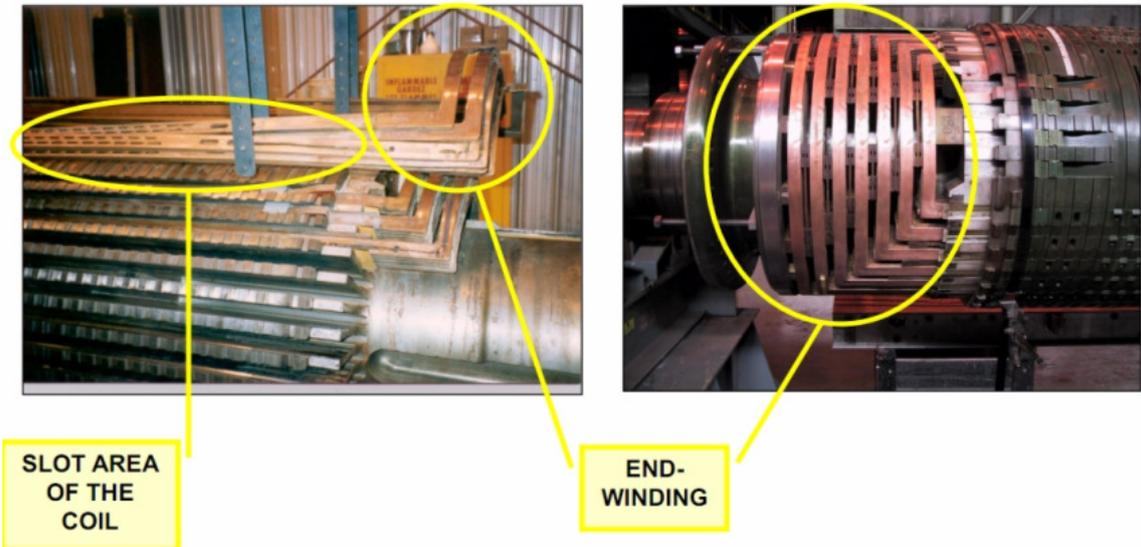


**Figure A2.7 Cross-section of a cylindrical rotor showing the magnetic poles and current flow in slots**

The next figures show examples of 2 cylindrical rotors with the end rings removed to expose the copper bars in the end regions of the rotor winding. The locations of the magnetic poles are clearly marked.



**Figure A2.8 Rotor end regions showing locations of magnetic poles**



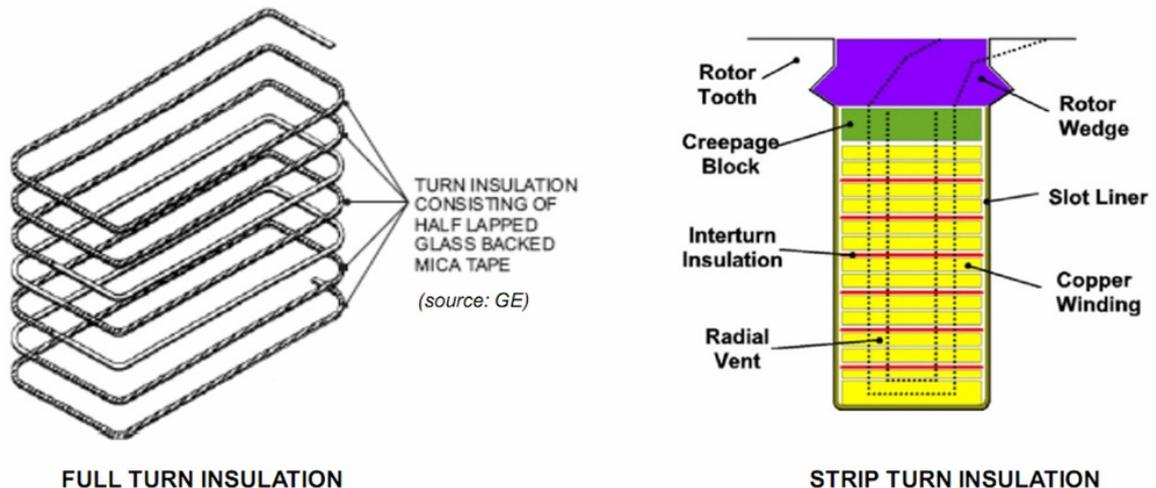
**Figure A2.9 Typical field winding showing both the middle (slot) and end winding sections. \***

(Some of the turns are shown lifted from the slots.)

\* Content from EIC conference proceedings June 2011 paper by I. Kersenbaum PhD, PE

## A2.4 WINDING AND INSULATION DETAILS FOR A SINGLE COIL

The next figures \* show how a single coil of 7 turns is constructed.



**Figure 2.10 Construction of a single coil in a rotor winding \***

\* Content from EIC conference proceedings June 2011 paper by I. Kersenbaum PhD, PE

Most large generators use the strip turn insulation method where insulation only exists between the main faces of the rectangular bars. The small sides of the bars are exposed but are isolated from the slot walls by an insulated slot liner..

The left-hand image shows one half-winding for Pole 1, which contains 7 coils. All of the turns and coils are connected in series. So each half-winding contains typically 56 turns. The half-windings are connected in series as shown in figure 2.4.

The length of individual turns will differ depending on the coil location because of the different circumferential separation of the rotor slot-pairs. In addition, there will be variations in length between the turns within each coil because of the different radial depths of the turns.

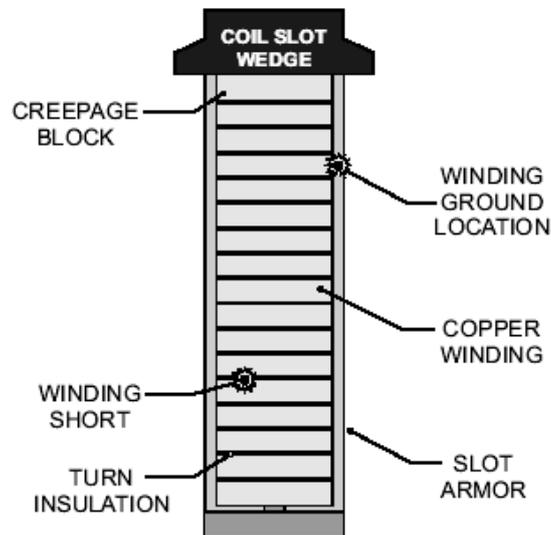
Using the above figures as an example, the normal winding configuration for each half-winding is as follows:

Coil 1 is the smallest coil, and is located next to the magnetic pole. The first turn in this winding (turn 1) is at the bottom of the radial slot and is connected to the slip ring or diode rectifier wheel by one of the insulated upshaft leads.

The coils are numbered sequentially outwards towards the ends of the rotor as shown in figure 2.8. The 2 half-windings are identical and they are connected together after the last coil in each half-winding (coil 7 in this case). For the rotors above, there will be a total of  $56 \times 2 = 112$  turns in the complete rotor winding.

## A3. ROTOR WINDING FAULTS IN LARGE ELECTRICAL GENERATORS

### A3.1 TYPES OF WINDING FAULTS



**Figure 3.1. Examples of coil insulation breakdown** (courtesy of GE Power Systems)

A 2-pole rotor rotates at 3000/3600 rpm to produce a 50Hz or 60Hz alternating voltage in the (3-phase) stator windings. The rotor windings experience large centrifugal forces, which can damage the insulation, leading to either faults from the winding to the rotor body ('**earth faults**') or faults between parts of the winding ('**inter-winding or inter-turn faults**') as shown in the figure above.

#### A3.1.1 Earth faults

An earth fault is often detectable with a simple multimeter and it may be possible to continue to operate a rotor having a single earth fault (preferably with some form of protection system to detect the onset of a second earth fault).

#### A3.1.2 Interturn faults

A rotor winding with a serious inter-turn may suffer heat damage at the fault location because any short between turns will have a significant resistance compared with the very small resistance of a single turn in the winding. Consequently, large quantities of heat can be generated at the fault location and this can cause damage to the remaining insulation, resulting in severe damage to the rotor windings. This subject is discussed further in section 3.3.

Inter-turn faults can also cause magnetic and thermal imbalance, giving rise to increased vibration levels. which may vary with the rotor (field) current and cause the generator to be taken out of service. They may also reduce the excitation capacity of the generator.

However, inter-turn faults often do not cause any obvious performance changes and are only found by monitoring or testing the generator as described later.

The existence of an inter-winding fault is not easily detected by simple electrical methods and specialised test methods are normally required.

### **A3.2 DETECTING AND LOCATING ROTOR WINDING FAULTS**

It is currently normal practice to test generator rotors routinely to detect these types of fault, both during construction and also before and after routine generator maintenance.

There are 2 standard methods in common use:

#### **A3.2.1 The Recurrent Surge Oscillograph (RSO) test.**

This is an off-line test which can both detect and locate both inter-turn and earth faults. It is a form of time-domain reflectometry and is carried out using a custom test instrument (**RSO reflectometer**). This is a **very sensitive test and will detect shorted turns which may not carry any significant current** in normal operation.

#### **A3.2.2 The Flux probe (search coil) test**

This test can be used to monitor an on-line generator where a suitable magnetic flux probe (search coil) has been pre-installed in the air gap between the rotor and stator. It will only detect a current-carrying shorted turn and will indicate the coil number containing the fault and the fault magnitude can also be estimated.

This test can also be used to test a rotor which has been removed from a generator following a repair. This is normally carried out at full speed during **rotor balancing in an overspeed pit**, using a temporary field current supply and slip rings.

### **A3.3. IMPACT ON PLANT OPERATION OF SHORTED TURNS**

The **RSO test** is very sensitive and will detect shorts between turns which do not carry any significant current. Consequently, some rotors may have many shorts without any serious impact on their operation, while the operation of others is impacted after developing a single fault.

The winding resistance for a large generator rotor is around 0.1 Ohms (100m  $\Omega$ ). As the rotor winding typically contains around 150 turns, the resistance around a single turn will be less than 1m  $\Omega$ . Consequently, a short between turns of 1 $\Omega$  will only carry 0.1% of the rated current. As typical large rotor currents are around 3000A, this will result in a current of only 3A through the short. If the short resistance value is 10  $\Omega$ , this current reduces to 0.3A.

The power (heat) dissipated at the short is calculated using  $P = I^2 \times R$  where P is the power dissipated, I is the current through the short and R is the short resistance.

For a  $1\Omega/3A$  short, the power dissipated will be 9 watts, and this amount of heat may be significant enough to burn the insulation.

For a  $10\Omega/0.3A$  short, the power dissipated will be 0.9 watts, which is unlikely to cause any problems on a large rotor winding.

If a shorted turn is detected by an RSO test, further tests will normally be required to determine whether the short is severe enough to carry significant current. A suitable method is to use a magnetic flux probe (search coil) which will only detect current-carrying shorted turns.

## APPENDIX 2

### FLUX PROBE (SEARCH COIL) TESTS

#### A2.1 INTRODUCTION

The **Flux probe test** is carried out with the rotor excited and at speed. The test monitors the rotor (magnetic field) windings of large power system generators and detects current-carrying inter-turn and double earth faults. It 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.

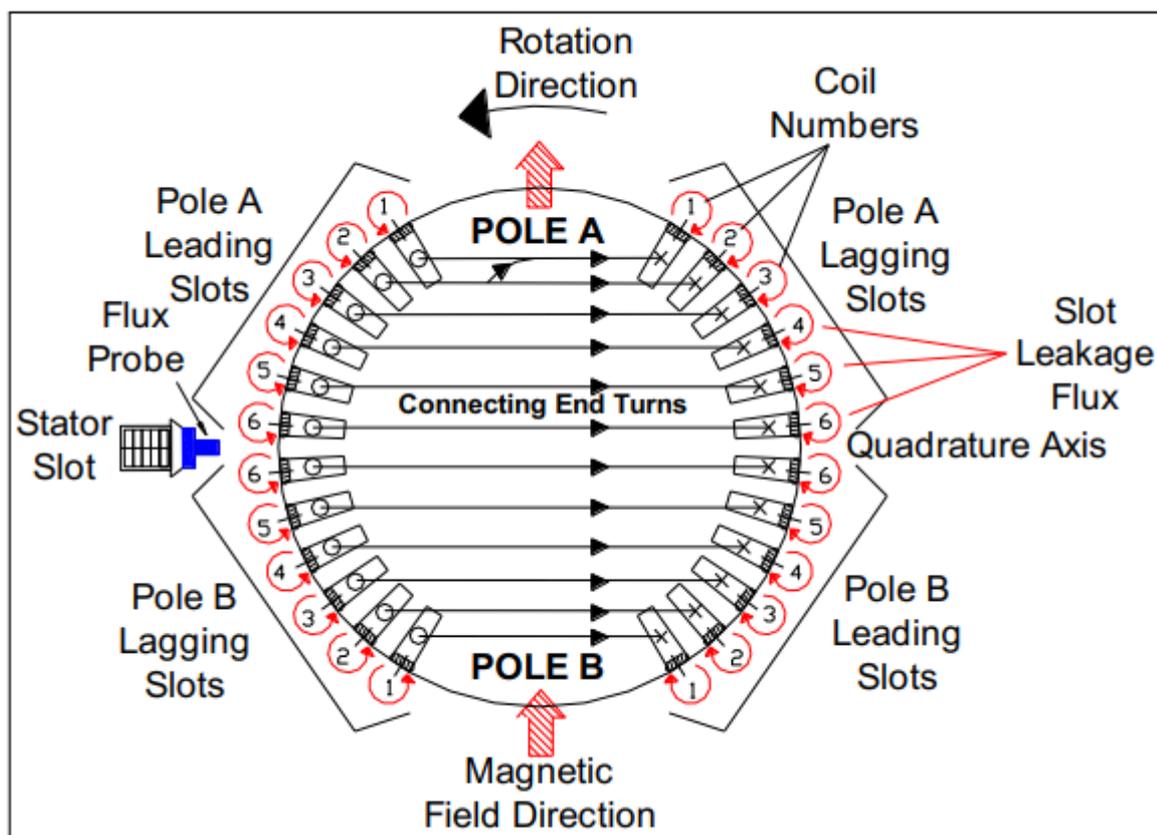
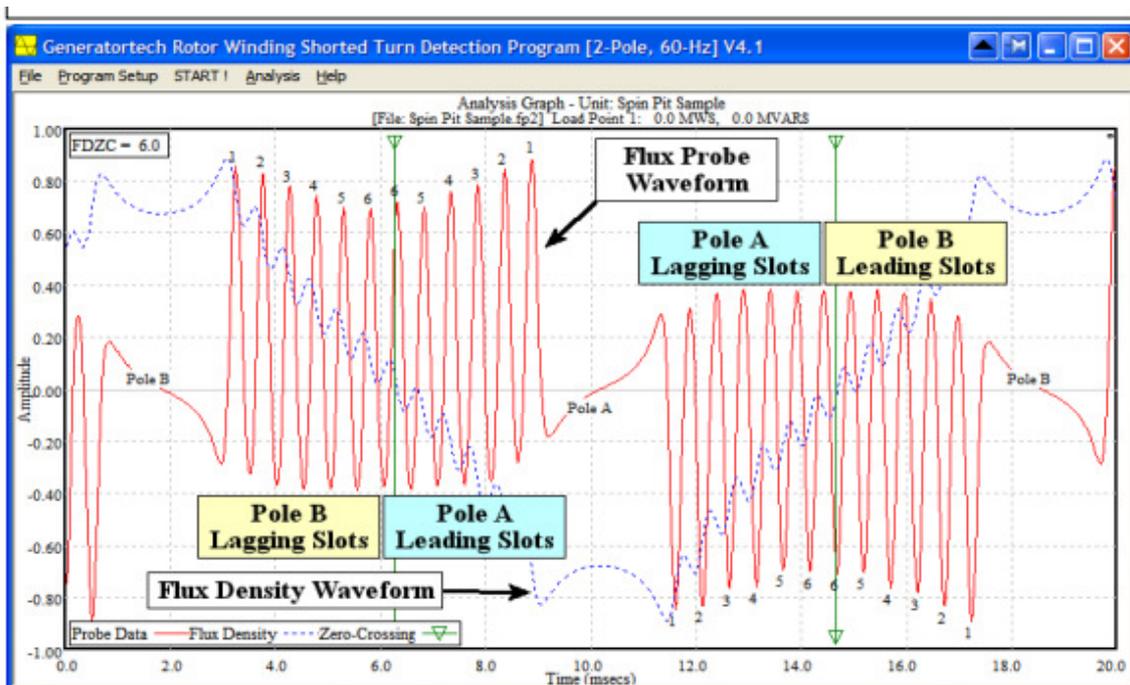


Figure A2.1.1 Cross-sectional representation of a cylindrical rotor. \*

Figure A2.1.1 shows the cross section of a 2-pole cylindrical rotor with 6 coils per pole, and the 2 magnetic poles A and B and also a small search coil (magnetic 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.A2.2.2.

\* From Generatortech publication.



**Figure A2.1.2 Output signal from flux probe \***

In the polar regions (A and B) , the magnetic field is fairly uniform and the coil output varies only slowly.

However in the coil slot regions between the poles, the magnetic field changes rapidly between each subsequent coil slot, producing a high frequency ripple signal as shown. This flux probe waveform is typical of that 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 while the leading slots precede these same pole regions.

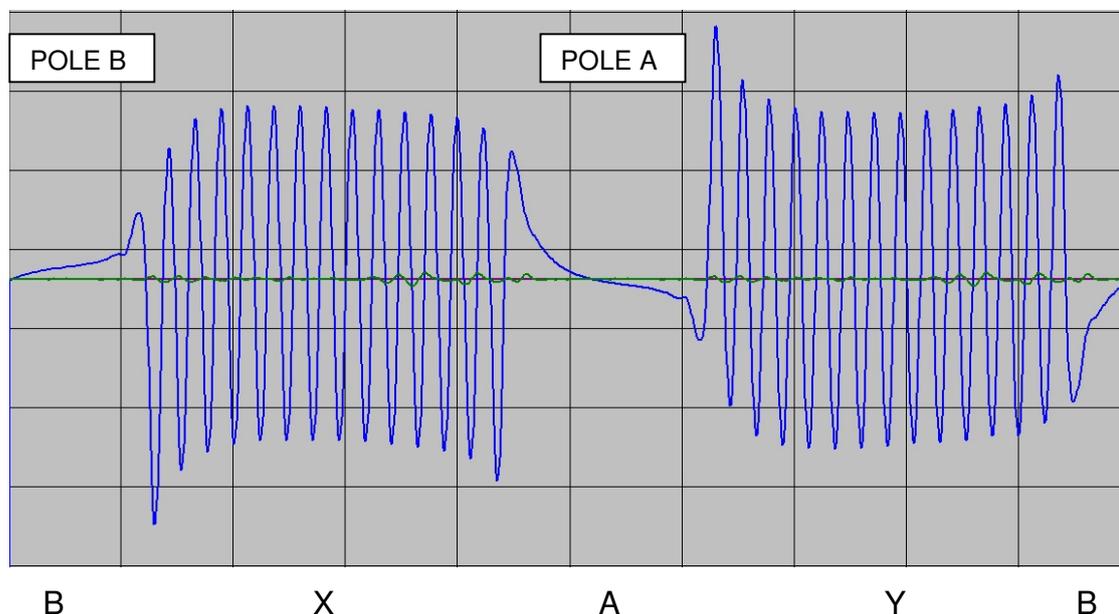
The output signal from the flux probe search coil installed in the alternator air gap (or a probe coil located close to the rotor surface for a rotor in an overspeed pit) is usually processed by a custom instrument to produce a nulled waveform for a sound generator. However, a field winding with a current-carrying inter-turn fault will display a series of peaks in the "Difference" waveform, corresponding to the position of the faulty coil slot as described later.

The flux probe measurement technique has the advantage over alternative methods in that continuous on-load monitoring of the generator is possible and only current-carrying winding faults are detected. Furthermore, 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.

## A2.2 PRINCIPLE OF OPERATION

Figure A2.2.1 below, obtained from a fault-free generator having 8 coil slots per pole, 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. It contains 2 nominally symmetrical and sequential waveform groups corresponding to each half-circumference of the rotor centred on each of the poles. A and B.



**Figure A2.2.1 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 field produced by the excited rotor winding. The waveform in figure A2.2.1 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 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 search coils, this process is carried out by delaying the search coil waveform by 180 degrees and adding or subtracting the delayed waveform to/from the undelayed

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 A2.2.1 is the result of adding the A pole half-waveform to the B pole half-waveform delayed by one half revolution.

### A2.3 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.

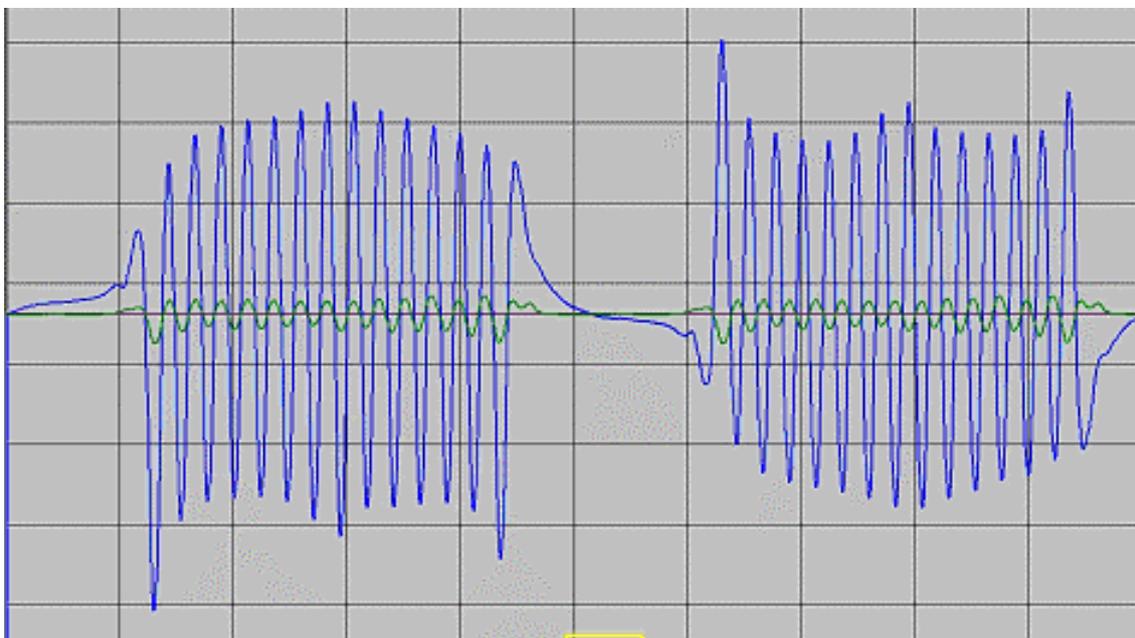
### A2.4 EFFECTS OF RESIDUAL MAGNETISM

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).

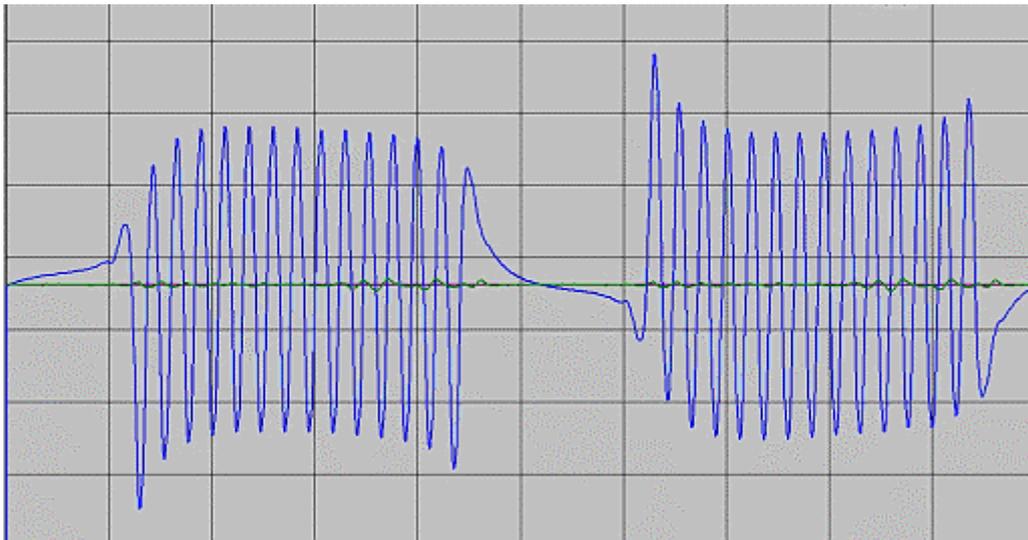
The waveforms in Figure A2.6.1 were obtained for a fault-free rotor (130 MW, 7 coils/pole) excited under test conditions with a restricted current of 27A at 3000 rpm..



**Figure A2.4.1 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 A2.4.2, the residual magnetism signal (obtained by running the rotor with no excitation) has been subtracted from the excited search coil waveform of figure 2.4.1. Note that the **Green** difference trace is now almost perfectly cancelled.



**Figure A2.4.2 Search coil waveform corrected for residual magnetism**

## REFERENCES

1. Albright, D.R. "Interturn Short-Circuit Detector for Turbine-Generator Rotor Windings", IEEE Transactions on Power Apparatus and Systems, Volume PAS-90 Number 2, March/April 1971.
2. False Turn Short Indications in Balance Pit Flux Probe Test. GeneratorTech Inc. publication.