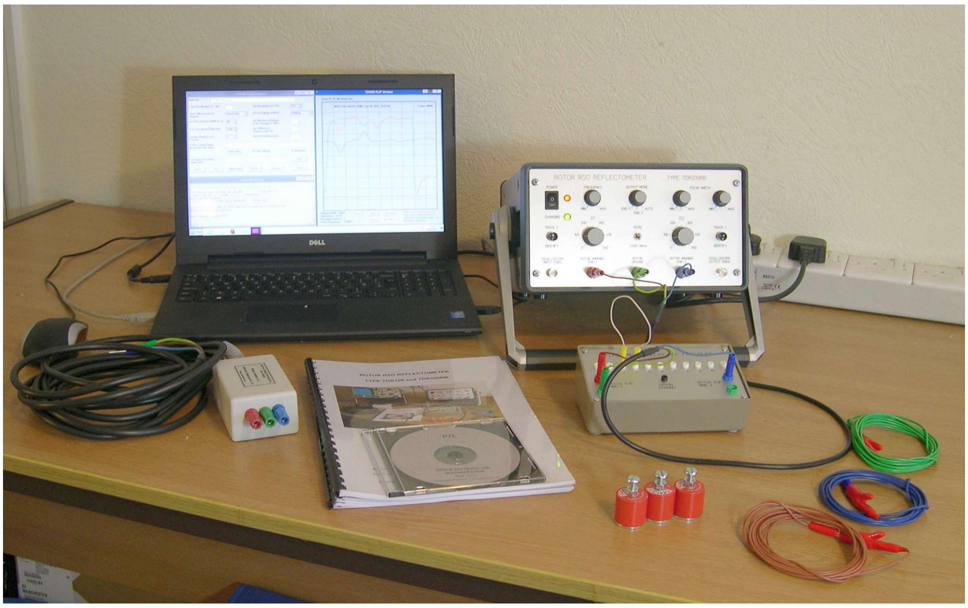
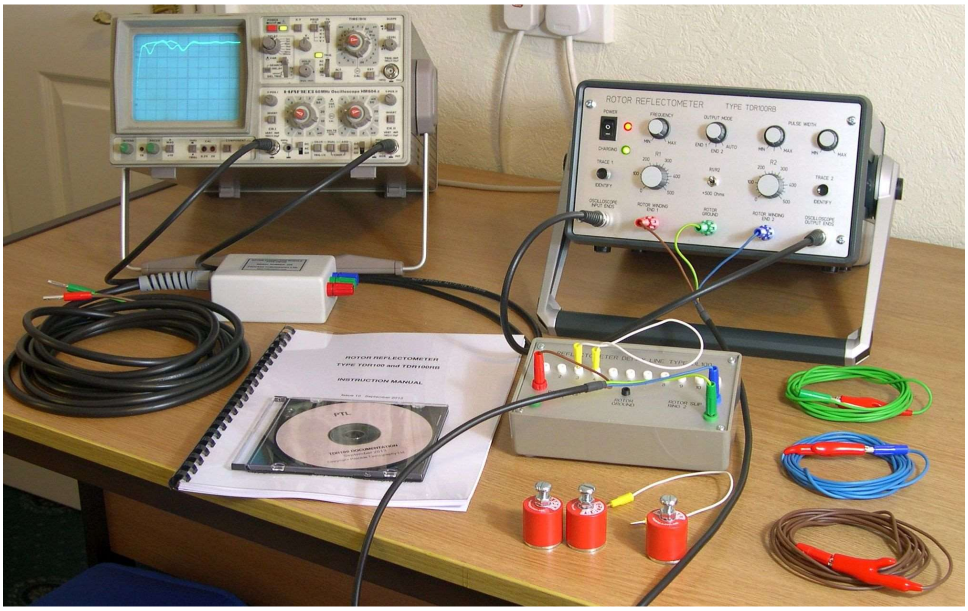
TDR200 ROTOR RSO REFLECTOMETER

USER GUIDE



OPERATION IN DIGITAL MODE



OPERATION IN ANALOGUE MODE

Rowtest Ltd.,

64, Courthill House, Water Lane, Wilmslow, Cheshire. SK9 5AJ. UK
Phone/Fax +44 - (0) - 1625 - 418722
Email: enquiries@rowtest.com   Website: www.rowtest.com

0. OVERVIEW OF THE MANUAL

This manual describes the operation of the **Rowtest TDR200 Rotor RSO Reflectometer** for **detecting and locating faults** in the **field windings** of **large cylindrical turbo-alternators** using the **RSO (Recurrent Surge Osillograph)** test method .

It is one of a pair of manuals, both of which are revised and updated versions of the previous set of **TDR200** instruction manuals.

This manual (The **TDR200 Rotor Reflectometer User Guide**) gives detailed advice and instructions for the use of the **TDR200 RSO measurement system** in both of its **Analogue** and **Digital** operating modes.

Its partner manual is the **Rowtest TDR200 Reference Manual ("Detecting and locating faults in the Rotor windings of large electrical generator rotors"**), which is supplied with each **TDR200** system. It contains information about the construction of **large cylindrical turbo-alternator rotors** and explains how **winding faults** in these rotors can be detected and located.

New users are strongly advised to read this document before using the **TDR200** equipment for the first time.

There is some duplication of information between these 2 manuals to allow them to be read independently. Similarly, there is some duplication within the sections of this manual for the same reasons.

SAFETY WARNING

The use of the TDR200 equipment on a rotor installed in an operational generator must be carried out with the explicit permission and under the supervision of the local plant operator. All local safety rules and procedures must be complied with.

In particular, the equipment must only be connected to the generator rotor after the field supply has been disconnected and isolated in accordance with local safety regulations. Failure to comply with this instruction will damage the equipment and may endanger both the the plant and the operator.

This Equipment complies with the following EEC Directives:

2006/95/EEC Low voltage directive
2004/108/EEC EMC directive

ORGANISATION OF THIS MANUAL

The manual consists of **5 main Parts** which are summarised below. Each **Part** contains a number of **section topics** which are detailed in the **Contents list** which follows.

CONTENTS LIST

Part 1

This contains sections 0 to 4 which give an overview of the **RSO test** and describe how to use the **TDR200 system** with the supplied **DL100 custom delay line.** This allows new users to familiarise themselves with the **TDR200** in both its **digital** and **analogue** operating modes in an an office or laboratory environment without the need for access to a real rotor winding.

Part 2

This contains sections 5 to 8 which describe the operation of the **TDR200 control software** in detail.

Part 3

This contains sections 9 to 14 which contain practical information about using the **TDR200** to carry out **RSO tests on real rotors** under various testing conditions **at rest and at speed**.

Part 4

This contains sections 15 and 16 which describe how to **locate winding faults** using the **RSO** test.

Part 5

This contains 3 appendices describing **software installation**, a **test result template** and some results obtained using a **physical model of a rotor winding**.

CONTENTS LIST

PART 1

PART 2

PART 5

APPENDIX 1 SOFTWARE INSTALLATION AND INITIALISATION (New PC only)

APPENDIX 2 RSO TEST REPORT BLANK TEMPLATE

APPENDIX 3 RSO TEST RESULTS FROM A ROTOR MODEL

PART 1

This contains sections 0 to 4 which give an overview of the **RSO test** and describe how to use the **TDR200** system with the supplied **DL100 custom delay line.** This allows new users to familiarise themselves with the **TDR200** in both its **digital** and **analogue** operating modes in an an office or laboratory environment without the need for access to a **real rotor winding**.

The 4 sections in Part 1 are as follows:

1. **An introduction to the RSO test** describing why the test is needed and what it can achieve.

This section first describes the **2 main types of faults** which can develop in the **field windings** of **turbo-alternator rotors**. This is followed by a d**escription of the principle of the RSO test** and describes in outline how it is implemented using the **TDR200** Rotor Reflectometer test equipment.

2. A "**Quickstart**" section demonstrating the use of the **TDR200** system operating in its **Digital mode** to carry out an RSO test using a simple **delay line** which simulates the characteristics of a **real cylindrical rotor winding**.

3. A similar **Quickstart** section describing the operation of the T**DR200** system in its **Analogue** mode.

4. Details of **the TDR200 RSO Reflectometer measurement system**. Includes further information about the **TDR200** system and information about measuring the **rotor electrical characteristics**.

0. OVERVIEW OF THE TDR200 RSO ROTOR REFLECTOMETER

0.1 THE RECURRENT SURGE OSCILLOSCOPE (RSO) TEST

The **RSO test** is an **off-line** test method which is used to detect and locate **rotor winding faults** on both **stationary** and **rotating** generators. It cannot be done **on-line** because the rotor winding must be **isolated** from the **exciter**. The RSO test is very effective in detecting and locating both **ground faults** and **shorted turns** in the field winding.

The operating principle is based on the fact that there is **electrical symmetry** in a **healthy rotor winding.** Consequently, if an **electrical pulse** is injected at either end of the rotor winding, the **travel time** through the winding and any **reflections of the pulse back to the input end** should be **identical**.

If there is an **interturn** or **ground fault**, some of the pulse energy will be **reflected back to the input ends** (**slip rings**) due to the drop in the **wave impedance** of the winding at the **fault location**. These reflections will change the **input pulse waveform** depending on the distance to the fault. Therefore, a **fault will generate different waveforms at each slip ring** (unless it is located exactly halfway in the winding).

In the **RSO** test, identical, fast-rising low-voltage pulses are injected either simultaneously or alternately at the slip rings. The pulse waveform at each injection point is plotted versus time on an oscilloscope or other suitable display device and identical waveforms should be obtained if there is no fault (due to the symmetry in the winding). **Differences between the waveforms** are indicative of a winding fault. The fault is **located** from the time at which the irregularity occurred.

The **RSO test** is **safe** and easy to use, with swift setup and measurement times. Only 3 connections to the rotor are required (to the slip-rings or their equivalent in brushless generators) and to ground. For rotors with slip rings, the test can be carried out with the **rotor at rest** and also **at speed**.

Typical applications include the routine testing of generators by **Electrical Power Utilities** and the monitoring by **manufacturers** and **repairers** of rotor windings during their initial fabrication and subsequent repairs. The **TDR200** Reflectometer can be left permanently connected to the rotor winding during re-insulation work, so that any defects are immediately apparent.

The **RSO test** should ideally be carried out on a routine basis so that any winding deterioration can be detected and correlated with other effects such as increased excitation current or mechanical vibration.

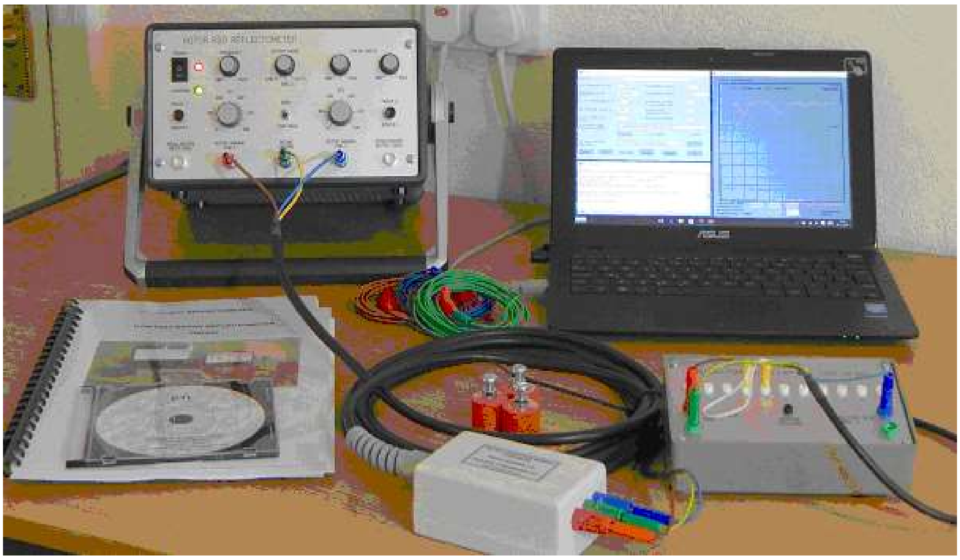
0.2 THE TDR200 ROTOR WINDING RSO MEASUREMENT SYSTEM

The **TDR200** measurement system is a development of the original **CDL TDR100 Rotor Reflectometer** which has been in use world-wide since 1978. The **TDR200** has all the functionality of the original version together with many enhanced features. It can operate in either the **original TDR100 analogue** mode with an **oscilloscope**, or in a **new digital mode** controlled by a **laptop PC** running custom **TDRPlot software**.

In digital **mode**, no oscilloscope is needed as the waveforms are displayed and stored on the **Control Laptop PC**. Both modes of operation are described in this manual, with emphasis on the **digital mode**. The **TDR200 Reflectometer** can be operated under **mains power** or from an **internal rechargeable battery**.

The **RSO test** can be carried out with the **unexcited** rotor winding **stationary** or **at speed** and is therefore particularly useful for detecting and locating faults which are speed-dependent.

0.3 TDR200 MEASUREMENT SYSTEM DETAILS



TDR200 Rotor winding RSO measurement system

The **TDR200** measurement system consists of a **Rotor reflectometer** and a set of **accessories** (see **section 0.4** for details) which can operate in either a stand-alone **analogue** mode or in a **digital** mode under control from **a custom laptop PC**.

The adjustment of the controls on the **TDR200 system** is non-critical. The **two RSO waveforms** at each end of the rotor winding are automatically displayed together in real-time on the **oscilloscope** or **PC screen** and it is **impossible to obtain two different RSO waveform traces for a fault-free rotor winding**, The **TDR200** has many advantages over conventional RSO test systems, including the following operational features:

The use of internal **rechargeable batteries** within the **TDR200** unit, together with a **notebook PC**, means that **no external power supply** is needed to carry out RSO tests with this equipment.

Trace ID buttons allow the **RSO traces** at each end of the winding to be identified and a **calibrated delay line** (supplied) allows the test system to be checked and calibrated without the need for access to a real rotor winding.

In **analogue mode**, non-alternating pulse-excitation modes can also be used.

When operated in **digital mode**, the equipment has further advantages:

Under **PC control** , the screen updates at rates up to 10 per second. This eliminates the problems which can occur when attempting to trigger digital oscilloscopes.

The **difference between the 2 RSO waveforms** can be plotted and displayed automatically.

An **on-screen cursor** provides **accurate time measurements** and **percentage differences** between the 2 RSO traces at **each cursor location** and a built-in algorithm gives an **estimate of the location** of any **winding faults**.

Averaging can be used to reduce the effects of noise due to brush contact problems.

An optional **persistence mode** allows waveforms to be compared directly, and the **averaging** option allows any waveform noise to be reduced.

RSO test results are saved automatically to both **text and bit-map image files** on program exit. They can also be saved to unique file names at any time during the test. These data files can be subsequently read and displayed in both the **TDRPlot** and other suitable software (eg MS Excel).

The **TDR200** can operate in both **real-time** and **playback** modes. In **real-time mode**, the software controls the equipment using the supplied custom **TDRPlot software** to display and capture RSO data. In **playback mode**, the same software reads and displays data from files captured during operation in real-time mode. This allows **saved RSO data** to be re-plotted and analysed. Custom setup files can be saved for individual rotors and this information is included within in each data file.

0.4 DETAILS OF EQUIPMENT SUPPLIED

The **TDR200** system includes a **demonstration delay line, set of connecting leads and magnets** for attaching the test leads to the rotor slip rings and shaft, a set of **instruction manuals** (in English), all contained within a **custom padded transit bag.**

The detailed list of equipment supplied is as follows:

TDR200 Rotor Reflectometer unit with IEC mains lead.

DL100 Demonstration Delay Line (inc. leads) (for demonstration, test and calibration purposes only).

Control Laptop PC with USB mouse and USB printer lead in laptop bag.

Terminal magnets (3) (for contact with slip rings and rotor shaft).

5m 3-core test lead terminated in a **connection module**.

3 x 3m single core leads (Brown, Green, Blue) terminated in 4mm insulated banana plugs (Red, Green, Blue) at one (connection module) end and insulated crocodile clips at the other (rotor) end.

2 x 1.2m Coaxial oscilloscope leads.

1m Delay line 4mm plug lead (red, blue, green)

Set of Instruction Manuals.

Software and documentation CD.

Padded Carrying Case.

1. INTRODUCTION TO THE RSO TEST

This section gives a brief introduction to the construction of **cylindrical rotor windings, rotor winding faults,** the **RSO test** and and the **TDR200 Rotor RSO Reflectometer** measurement system. A more comprehensive description of these topics can be found in the Rowtest "**Detecting and locating faults in the rotor windings of large electrical generator rotors**" **Reference Manual**.

1.1 CYLINDICAL GENERATOR ROTORS

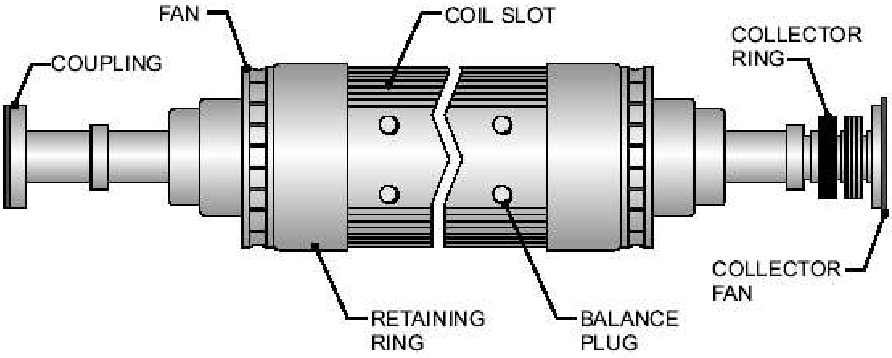


Figure 1.1.1 A typical generator field rotor (courtesy of GE Power Systems)

Large high-speed electrical generators use a rotating magnetic field produced by a rotor in the form of a cylindrical electromagnet having either 2 or 4 magnetic poles*. The rotor body is a solid steel forging containing radial slots for the coils which make up the electromagnets (rotor windings). The turns of the coils are rectangular copper bars insulated with an epoxy material and 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 15 turns of insulated copper bar) is shown in figure 1.1.2.

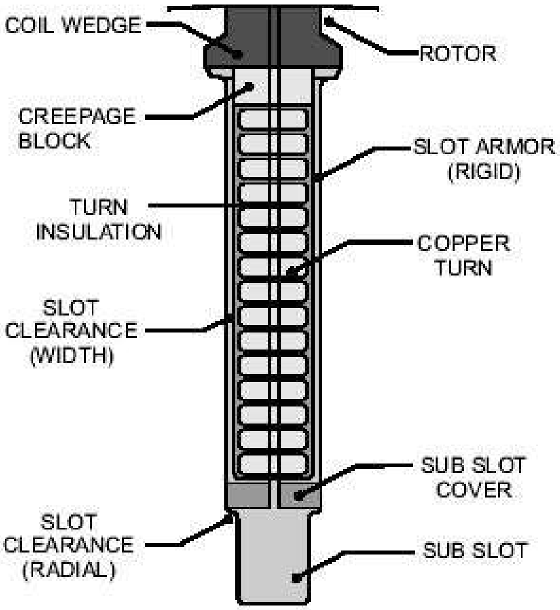


Figure 1.1.2 Cross-sectional view of a radial slot containing the rotor field winding. (courtesy of GE Power Systems)

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. 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.

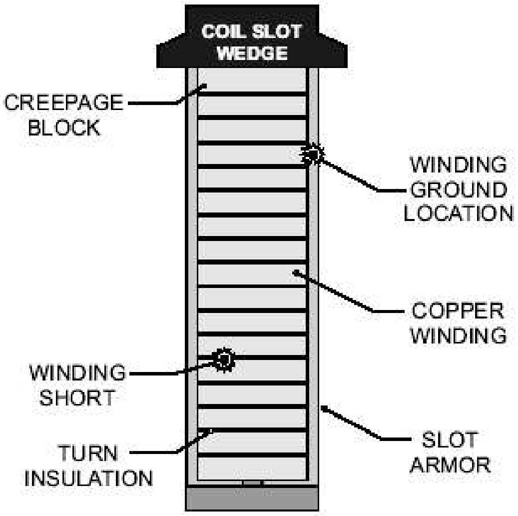


Figure 1.1.3. Examples of coil insulation breakdown (courtesy of GE Power Systems**)**

1.2 ROTOR WINDING FAULTS

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 shorts between the rotor winding and ground (**earth faults**) or between adjacent turns (**inter-turn faults**) as shown in the figure above.

An **earth fault** is detectable with a simple multimeter. A single earth fault on a rotor is frequently tolerated and many generators run in this condition (preferably with some form of alarm system to detect the onset of a second earth fault).

An **inter-turn fault** is not easily detected by simple electrical methods. However, as the DC field current is large and any short circuit will have finite resistance compared with that of one turn, the portion of the field current carried by the short may cause heat to be generated locally at the fault location. This can burn the remaining insulation, resulting in severe damage to the rotor windings.

Shorted turns can also cause cause magnetic imbalance, giving rise to increased mechanical vibration levels.

Generator rotors are routinely tested to detect these types of fault, usually during construction and also before and after routine generator maintenance. One standard test method used is **time-domain reflectometry**. However, unlike the similar technique used for testing transmission lines, a custom test instrument (**RSO Reflectometer**) is required, because the rotor winding is a very imperfect transmission line and produces a large number of reflections at each change in the **characteristic (wave) impedance** between the sections of conductors inside the radial slots and the sections in the cross-over end regions.

1.3 THE RSO TEST METHOD

The basis of the RSO test method to for testing rotor windings for earth faults or shorted turns was first described by **A.E Grant** in 1973 and a copy of this paper is included in **Appendix 1** of the **TDR200 Reference Manual**.

The RSO method relies on the fact that the rotor winding is symmetrical. For example, a 2-pole rotor contains two nominally-identical half-windings, one for the North pole and the other for the South pole, both of which are connected in series. A four pole rotor is similarly symmetrical.

This symmetry property is used to compare the response of the 2 halves of the rotor winding to a short voltage pulse applied between each slip-ring and the rotor body. The pulses and any reflected signals are displayed at each end of the rotor winding using a suitable **waveform monitor** such as an **oscilloscope** or **PC screen**. If the rotor winding is fault-free, two identical waveforms will be observed at each slip ring. However, if one half-winding contains a fault, the two waveforms will differ. The test details are described below.

The **TDR200 RSO Reflectometer** applies a low-voltage pulse (12V) between one of the rotor slip rings and ground and the transmitted pulse received at the remote end of the rotor and the reflected pulse waveforms at the sending end are displayed on a waveform monitor as shown below.

A pair of adjustable matching resistors are used to test the rotor winding under repeatable conditions and are normally set so that the pulse generator and terminating resistor match the characteristic impedance of the rotor winding (typically values in the range 30 - 1000 Ohms).

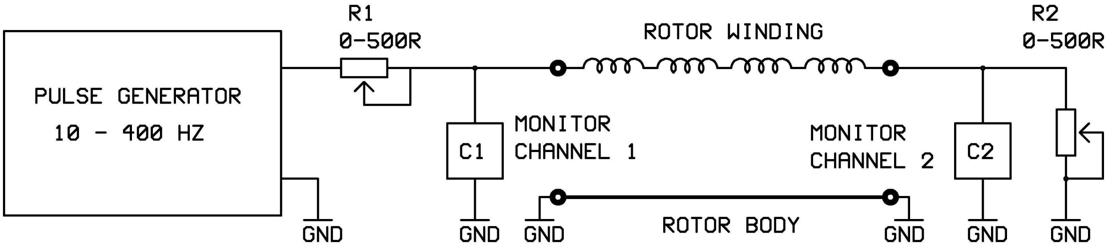


Figure 1.3.1 Rotor winding test method

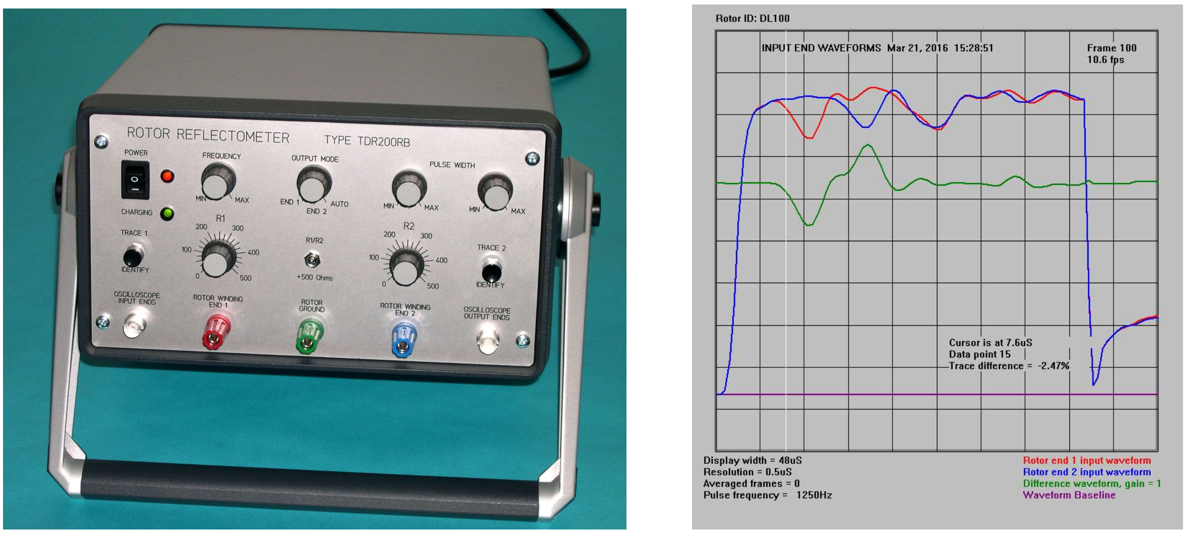
The tests are carried out by applying pulses from each end of the rotor winding in turn and the monitor traces are recorded and compared. If the rotor is fault-free, the monitor traces will be identical.

In practice, the **TDR200** test instrument has a switching circuit which applies pulses alternately from each end of the rotor winding so that the waveforms are automatically superimposed when viewed on a single channel oscilloscope. This is described in detail in the next section.

Note: The easiest way to gain familiarity with the RSO test method is to use a custom **Delay line**, which simulates a real Rotor winding. Full details are given in sections 2 and 3 of this manual.

1.4. THE TDR200 ROTOR WINDING RSO REFLECTOMETER OPERATING PRINCIPLE

The **TDR200** is a customised reflectometer which uses the **RSO test method** to detect and locate faults in generator rotor windings. The **TDR200** can operate in either an **analogue mode** with an **oscilloscope** or in a **digital mode** controlled by a **laptop PC**.



Rotor ID: DL100

INPUT END WAVEFORMS Mar 21, 2016 15:28:51

Frame 100
10.6 fps

Cursor is at 7.6uS
Data point 15
Trace difference = -2.47%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Rotor end 1 input waveform
Rotor end 2 input waveform
Difference waveform, gain = 1
Waveform Baseline

Figure 1.4.1 THE TDR200 Rotor Winding RSO Reflectometer and example RSO waveforms (in digital mode)

A schematic of the basic TDR200 Reflectometer system is shown in Fig. 1.4.2. A pulse generator supplying a 12V pulse of variable length at a repetition rate of up to 400Hz is connected via a 500Ω variable resistor to an electronic changeover switch S1 synchronised to the pulse repetition rate.

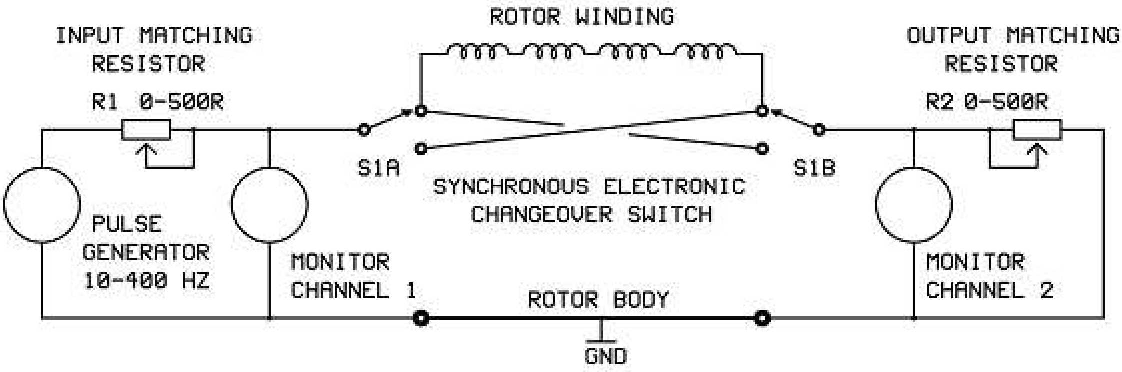


Figure 1.4.2 TDR200 Reflectometer operating principle

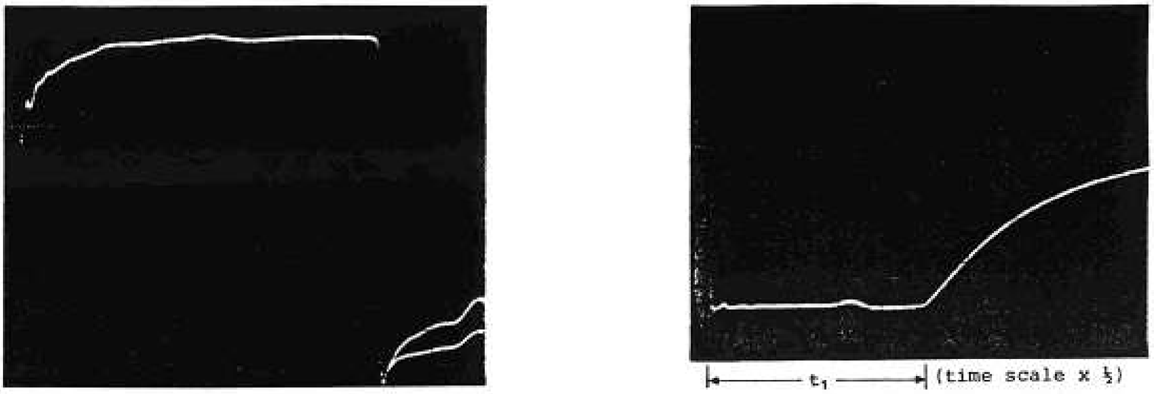
The changeover switch enables the rotor to be excited from each end of the winding in turn, alternate pulses exciting the rotor from opposite ends. The rotor is terminated in a second variable resistor R2 via the changeover switch. The pulse generator, synchronous changeover switching network, matching resistors and terminals are all contained within the Reflectometer unit.

Two measurement channels display the voltage at the input ends of the rotor (channel C1) and at the output ends (channel C2). The values of R1 and R2 are chosen to match, approximately, the **characteristic wave impedance** of the rotor winding, to eliminate reflections of the pulse at each end of the rotor.

1.5 EXAMPLES OF MEASURED RSO WAVEFORMS (ANALOGUE MODE)

1.5.1 Measured RSO waveforms for a fault-free rotor winding (analogue mode)

Figure 1.5.1 shows the RSO waveforms at the **inpu**t and **output ends** of a fault-free rotor winding. These results were obtained with the reflectometer operating in **analogue mode** with an **oscilloscope** and in both cases show **2 perfectly superimposed RSO waveforms.**



Input ends **Output ends**

Figure 1.5.1 Typical oscilloscope traces for a fault-free rotor winding

Although the pulse injected at the **input to R1** is a square waveform, the waveform at the **output of R1** (the input ends of the winding) is no longer square because of multiple reflections from impedance changes along rotor the winding. The waveform at the **output ends** of the winding is a delayed and distorted slowly rising version of the input pulse.

The **injected pulse** will take a finite amount of time (the **transit time**) to travel from the **input end** of the rotor to the **output end**. As a result, the waveforms monitored by C2 will display zero voltage for this period (the transit time) and the transit time can therefore be measured directly from the C2 traces.

Figure 1.5.2 below shows simplified versions of these waveforms A sound rotor will appear to be symmetrical with respect to either slip ring and therefore, the two traces that either C1 or C2 display will be identical and can be superimposed on the monitor screen.

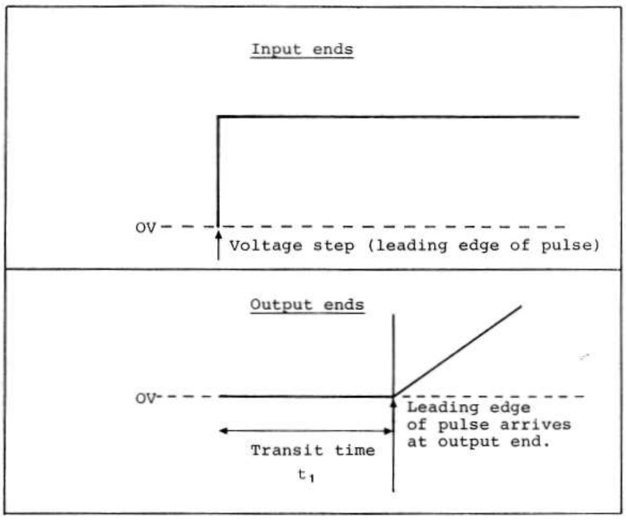


Figure 1.5.2 Simplified oscilloscope traces for fault-free rotor winding

1.5.2 Measured waveforms for a rotor winding with an earth fault

When an earth fault occurs part way along the winding, the traces that occur are shown as measured, in Fig. 1.5.3 and in simplified form in Fig. 1.5.4.

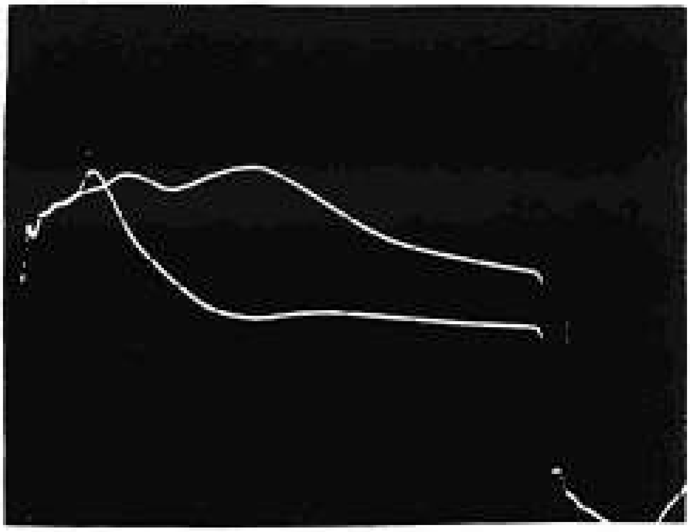


Figure 1.5.3 Short circuit to rotor body at end of 5th coil slot (16 coils in winding)

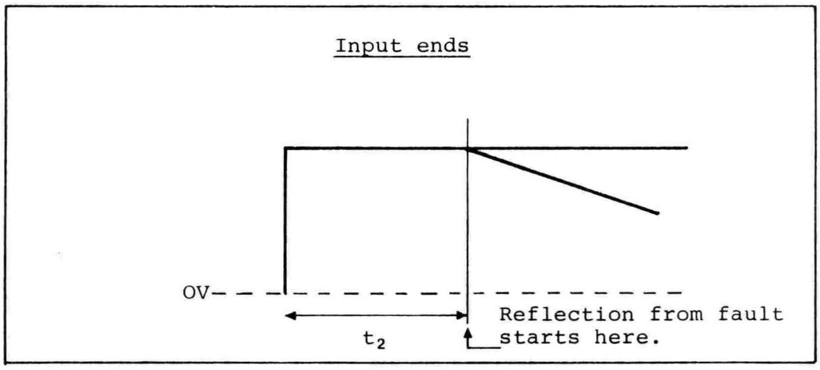


Figure 1.5.4 Simplified input end oscilloscope traces for rotor winding with earth fault

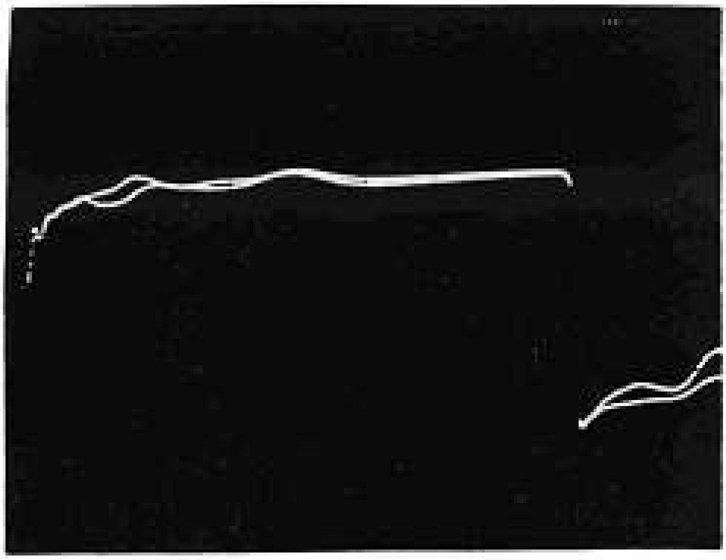
At the short circuit to earth, the input pulse is reflected with reverse polarity and when it returns to the input end, a decrease in voltage is observed. Assuming that the fault is not exactly in the centre of the winding, the reflection will occur at different positions for the two traces. The traces will therefore diverge as shown in Fig. 1.5.3. The trace that is deflected first corresponds to the end nearest to the fault. A rough estimate of the position of the fault may be found by noting the time to the fault as indicated by the input trace ($\mathbf{t_2}$ seconds).

By linear scaling, the fault will be approximately $\mathbf{t_2 \,/\, (2t_1)}$ x 100% of the winding from one end. However, the apparent propagation velocity of the pulse through the rotor winding is not uniform and care must therefore be exercised in locating faults by this method, as explained later **in section 15.**

An improved method for locating the position of the fault is outlined in **Section 16**. This involves removing the rotor from the generator and probing the winding in the end region or down the radial cooling holes if these exist. The detection and location of interturn faults may be carried out in a similar manner.

1.5.3 Measured waveforms for a rotor winding with an interturn fault

If there is an interturn fault, the waveform at the slip ring nearest the fault is characterised by a slight increase in voltage followed by a decrease down to a minimum, followed by a slow voltage rise, as shown in the figure below.



(b) Short circuit between outer two turns in 5th slot coil.

Figure 1.5.5. Measured waveforms for a rotor winding with a single shorted turn.

1.5.4 Impedance change at a shorted turn

The shape of the traces for an interturn fault can be explained by considering the effect on the incident pulse of a single shorted turn, as shown in the figure below.

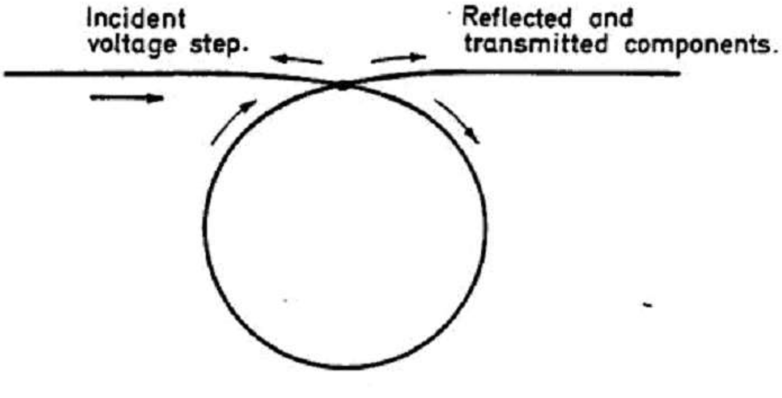


Figure 1.5.6 Simple representation of a shorted turn

When the pulse reaches the short circuit between the turns, it can take one of 3 paths in the forward direction, instead of a single path in the fault-free case. The wave impedance that the pulse sees looking in the forward direction will therefore be Zo/3, where Zo is the characteristic wave impedance of the winding

This causes the transmission line to appear unmatched at this point and a proportion of the voltage will be reflected with opposite polarity to the incident pulse, leading to a decrease in voltage when observed at the input end.

However. the rest of the pulse will propagate away from the short circuit and two of the three paths available (round the shorted turn) will return the pulse to the point of the short circuit.

Part of this pulse will then be returned to the input end of the winding leading to an Increase in voltage. The part of the pulse which travels round the shorted turn will do so continuously, causing the energy to be returned to the main rotor winding over an extended period of time.

The next section gives examples of similar waveforms with the **TDR200 Reflectometer** operating in its **digital mode**.

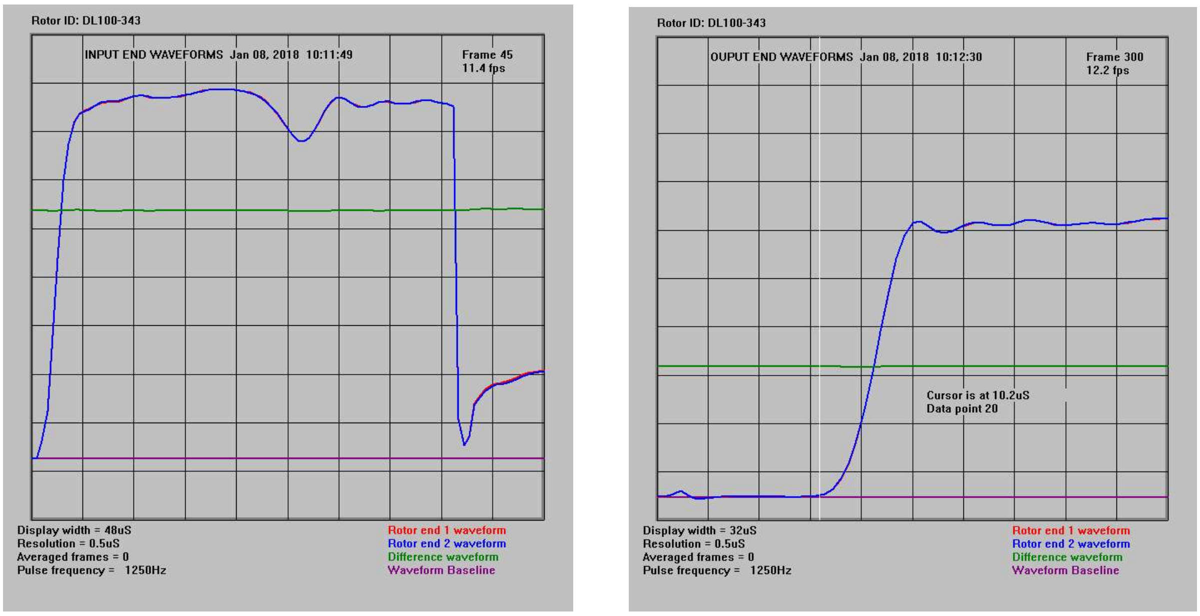
Further details of the waveforms resulting from various fault conditions are shown and discussed in later sections.

Note that the design of rotors for large hydro-electric generators differs from that described above as they **rotate at lower speeds** and have **multiple sets of magnetic poles**. They usually have **laminated cores** which **invalidate the transmission line model**. However, in some cases, these types of windings can be tested in the same way as for high-speed turbo-generator rotors.

1.6 EXAMPLE RSO WAVEFORMS OBTAINED USING THE DL100 DELAY LINE

The following test results were obtained with the **TDR200** operating in **digital mode** using the **TDRPlot software** running on a **Laptop PC** with the **DL100 Delay line** simulating a real rotor winding. Note that the **RSO waveforms** obtained for a **real rotor** will show **smaller trace differences** under fault conditions (see section 11.9).

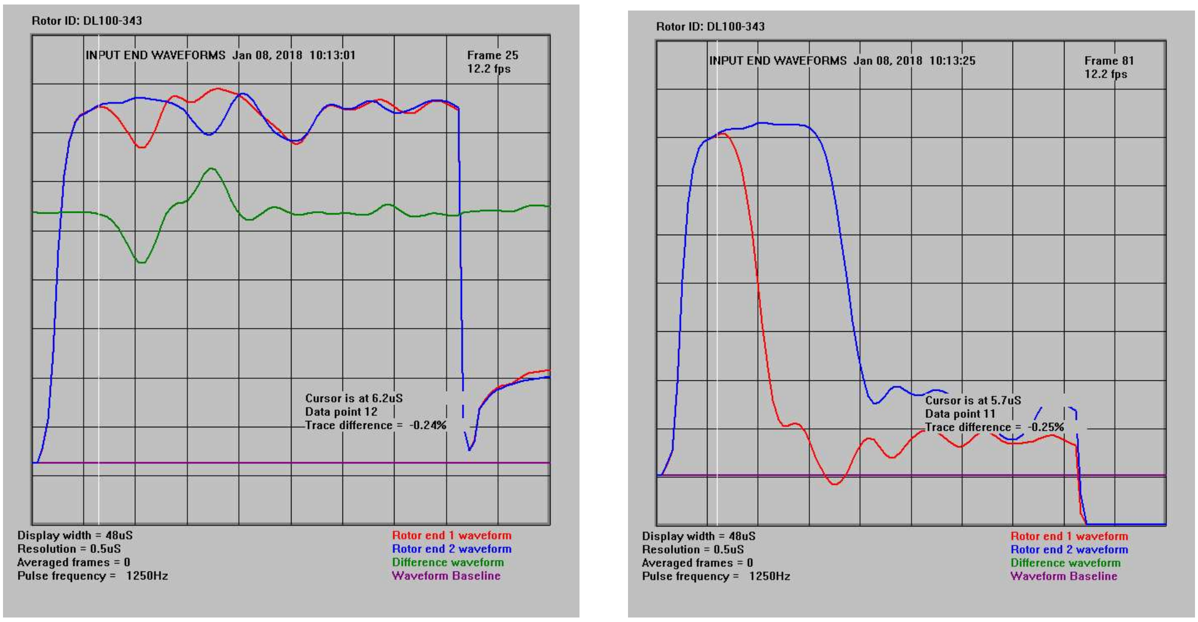
The **red waveform** corresponds to the **RSO waveform** at **end 1** of the rotor winding, The **blue waveform** corresponds to the RSO waveform at **end 2** and the **green waveform** is the difference between the red and blue waveforms.



(a) No Fault. Input ends **(b) No Fault. Output ends**

Figure 1.6.1 RSO waveforms for a fault-free rotor in digital mode

For a fault-free rotor winding, the Green (difference) trace should be a horizontal straight line as shown in figure 1.6.1(a).


Rotor ID: DL100-343
INPUT END WAVEFORMS Jan 08, 2018 10:13:01
Frame 25
12.2 fps
Cursor is at 6.2uS
Data point 12
Trace difference = -0.24%
Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz
Rotor end 1 waveform
Rotor end 2 waveform
Difference waveform
Waveform Baseline

Rotor ID: DL100-343
INPUT END WAVEFORMS Jan 08, 2018 10:13:25
Frame 81
12.2 fps
Cursor is at 5.7uS
Data point 11
Trace difference = -0.25%
Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz
Rotor end 1 waveform
Rotor end 2 waveform
Difference waveform
Waveform Baseline

(c) Simulated shorted coil (4-5) **(d) Simulated earth fault (4 - G)**

Figure 1.6.2 RSO waveforms for interturn and earth faults in digital mode

Interturn and **earth faults** cause the RSO traces to **diverge** as shown in figure 1.6.2. The white cursor measures the **time** at which the traces start to diverge.

1.7 THE TDR200 ROTOR RSO REFLECTOMETER OPERATION DETAILS

Figure 1.7.1 THE TDR200 Rotor Winding RSO Reflectometer

The main component of the **TDR200** measurement system is the **TDR200 Rotor Reflectometer** shown in figure 1.7.1 above.

The reflectometer can be operated either from its **internal battery** alone or while the battery is **being charged** from a local mains supply. The **mains supply switch** is on the **rear panel** of the reflectometer and the **battery on/off switch** is located on the **front panel**.

The operation of the reflectometer is described in detail in later sections for both its **analogue** and **digital** modes.

The normal method of operation of the TDR200 Reflectometer is in **digital mode,** where the reflectometer is connected to and controlled by a PC running the **TDRPlot software**. In this case, the **pulse repetition rate** is set by the **Control PC** and the **waveforms** are **captured**, digitised and sent to the **PC** via a **USB interface** by the **TDRPlot software.** This displays the waveforms at the **input** or **output** ends of the rotor windings and saves them as either **bitmap** or **text data files**.

The **difference between the waveforms** can also be displayed, and this **difference plot** should be a **straight horizontal line** for a **fault-free rotor winding**. The **horizontal plot width** of the displayed waveforms is calibrated and **cursors** can be used to accurately measure **time delays** and **percentage waveform amplitude differences** at points of **trace divergence**. A **locate** algorithm can also be used used to estimate the **position of any winding faults**.

1.7.1 ADDITIONAL OPERATING MODES (ANALOGUE MODE ONLY)

Although the normal operating mode of the **TDR200** system is **Auto** (pulses injected alternately from each end of the winding in turn) **mode**, it is possible to apply pulses to either **slip ring 1** or **slip ring 2** only when in **analogue mode**.

This option can be useful when using a **digital oscilloscope** to monitor the traces as described in **section 12.5**.

In **Digital mode**, the **Mode switch** must be set to **Auto** as no waveforms will be displayed on the PC in the other 2 modes

The operating mode is controlled by the 3-way **Output Mode switch** as follows:

Position **'END1'**	-	pulses are injected into slip ring 1 only.
Position **'END2'**	-	pulses are injected into slip ring 2 only.
Position **'AUTO'**	-	**normal operating mode.** (Pulses injected at **alternate ends**)

For normal rotor testing ensure that this switch is in the **'AUTO**’ position, as the single trace produced when the switch is in the **'END1**’ of **'END2**’ position will not indicate a winding fault.

When in the **'AUTO**’ position always check that two traces are present by using the '**Trace Identify**’ buttons. If only one trace is shown when one button is pressed, check and adjust the triggering of the oscilloscope (particularly when using a digital oscilloscope).

The following sections give details of the **controls** and **terminals** etc. on the front and rear panels of the unit.

1.7.2 CONTROLS, INPUTS AND OUTPUTS ON FRONT PANEL

Figure 1.7.2 TDR200 Front Panel controls and connectors

Power switch: Turns on instrument

Supply on LED (Red):

Charging LED (Green): Battery is being charged

Frequency control: Controls pulse repetition rate (in analogue mode only)

Output Mode: Pulse injected from **End 1 only, End2 only** or **Alternate ends**

Pulse width range rotary switch: Controls width of applied RSO pulse

Pulse width control: Fine control of RSO pulse width

Input end matching impedance control R1: (0 - 500 Ohms)

Trace 1 ID push button switch: Displaces RSO trace at end 1 only

Output end matching impedance control R2: (0 - 500 Ohms)

****R1/R2 Characteristic Impedance (Z0) range extend switch**: + 500 Ohms

Output end matching impedance control R2: (0 - 500 Ohms)

Trace 2 ID push button switch: Displaces RSO trace at end 2 only

**** Z0** is typically in the range 30 - 1000 Ohms and so an **additional switch** on the **TDR200 front panel** is provided which allows a pair of fixed 500 Ohm resistors to be switched in series with both R1 and R2 to extend the impedance matching range if required.

1.7.3 CONNECTORS ON FRONT PANEL

Oscilloscope Input ends (BNC) : Output to oscilloscope channel 1

Rotor winding end 1 (Red 4mm terminal): Connection to rotor slip ring 1.

Rotor ground (Green 4mm terminal): Connection to rotor shaft

Rotor winding end 2 (Blue 4mm terminal): Connection to rotor slip ring 2.

Oscilloscope Output ends (BNC) : Output to oscilloscope channel 2

1.7.4 ITEMS ON REAR PANEL

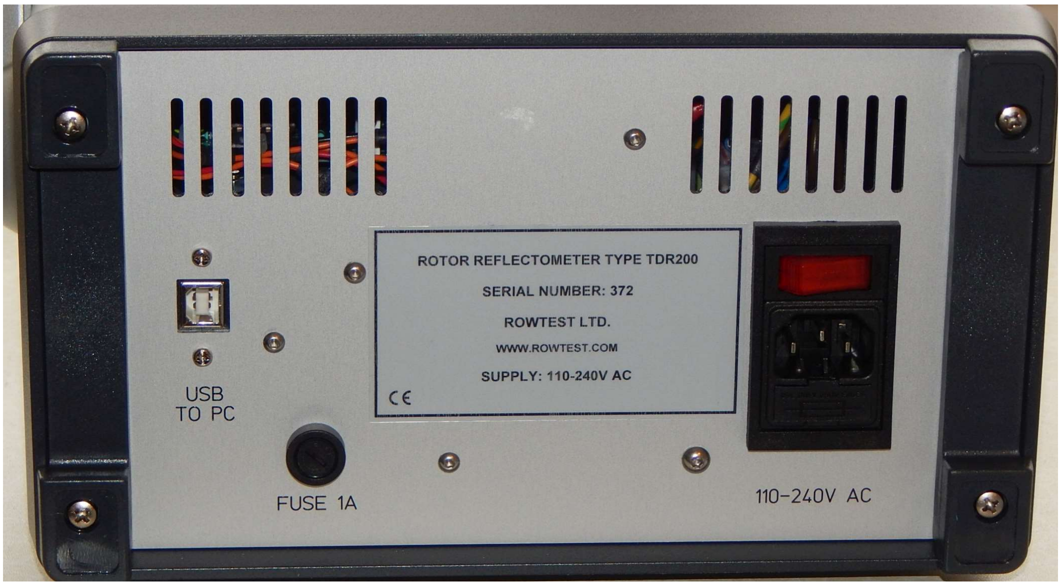


Figure 1.7.3 TDR200 Rear Panel

Mains input IEC switch and fuse unit.

USB B connector : To Control PC

1.7.5 TDR200 SPECIFICATIONS

POWER OPTIONS	110-240V AC, 50-60Hz, or from an internal maintenance free rechargeablebattery pack with an integral charger, giving over 8 hours continuous use under average operating conditions.
IMPEDANCE MATCHING RANGE	5 ohms to 500 ohms or 500 ohms to 1000 ohms.
PULSE RATE	40Hz to 200Hz continuously variable (analogue mode) or as set on the **Control PC** (digital mode).
PULSE WIDTH	20µS to 400µS in three switched ranges.
PULSE AMPLITUDE	12V nominal
ENCLOSURE	Two-tone grey metal case with adjustable carrying handle.
DIMENSIONS:	
Reflectometer only:	W: 320mm H: 155mm D: 360mm inc. handle.
Total system Weight:	Approximately 15kg
ACCESSORIES	Supplied in padded transit bag with manuals, leads, contact magnets and Delay Line (DL100).
***Laptop PC:**	Standard Windows laptop PC in case.

* NB. The laptop PC is optimised for use with the TDR200 system and is not suitable for use as a general-purpose PC.

2. QUICKSTART INSTRUCTIONS (DIGITAL MODE)

In this section we describe how to set up and demonstrate the use the **TDR200** in digital mode using the **DL100 demonstration delay line.** This section is suitable for first users of the equipment as it allows familiarisation with equipment without the need for access to a rotor. Detailed operating instructions for using the equipment on an actual rotor are given later in **sections 9-14**.

Important Note: The **DL100** delay line is used for **demonstration** and **calibration** purposes only. It is not used to test a real rotor winding. For full details **of the delay line,** please refer to **section 5** of the **TDR200 Reference Manual**.

2.1 THE DEMONSTRATION DELAY LINE

The delay line unit, which simulates and approximates to a real rotor winding, is used to check that the Reflectometer is operating correctly and is also an aid to demonstrating and understanding the RSO test method. It is a 10 section lumped component delay line with a characteristic impedance of 100 ohms. The propagation time for a single pass through the unit is approximately 10 ohms. The junctions between each section of the delay line are connected to a series of white 2mm sockets, enabling external connections to be made to these points using a **patch lead**. The input and output ends of the unit are connected to 4mm sockets as shown in figure 2.1.1 below.

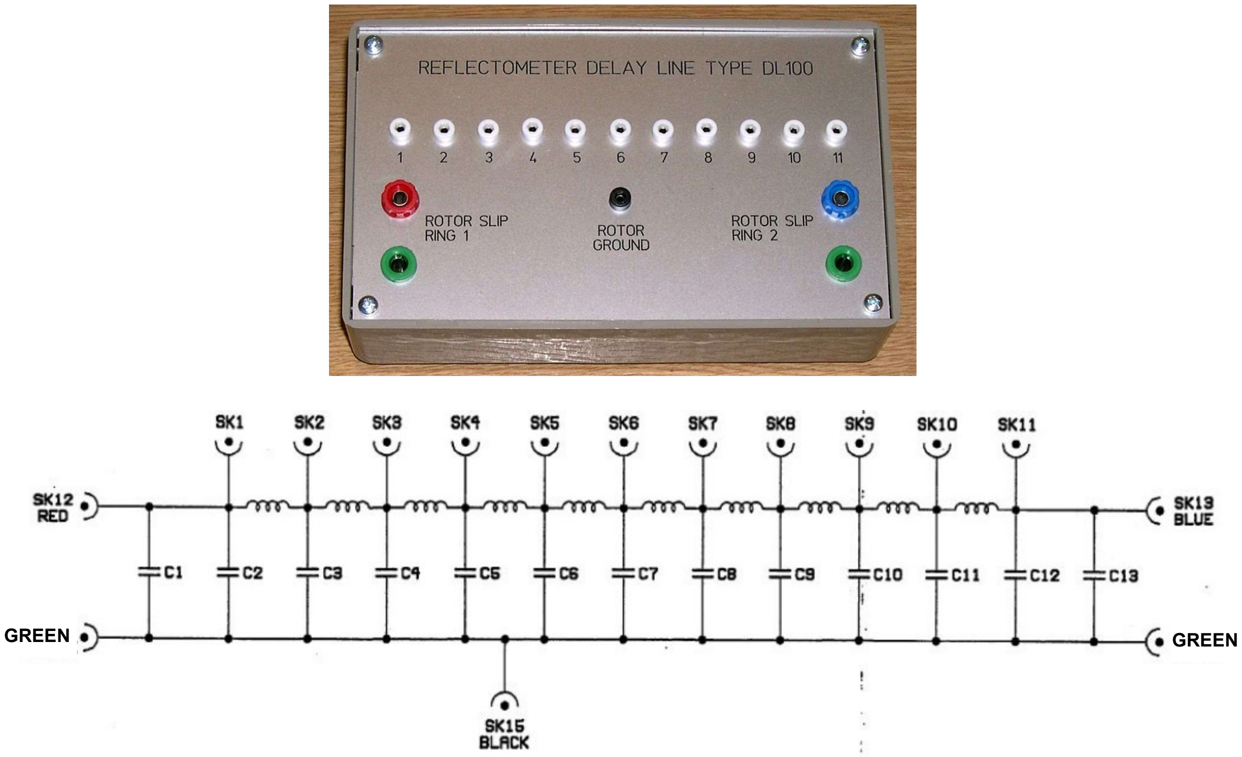


Figure 2.1.1 Delay line type DL100

In use, the **Delay line** is connected to the **Reflectometer** using the **1m 3-core test lead** supplied and shown in figure 2.1.2. At the **Delay line** end, the **red banana plug** is connected to the **red (slip ring 1) terminal** on the delay line, the **blue banana plug** is connected to the **blue (slip ring 2) terminal** and the **green banana plug** is connected to one of the **green common (ground) terminals**. The same plug colour convention is used to connect this lead at the reflectometer end, as shown in figure 2.2.1

Figure 2.1.2. 1m delay line connection lead

2.2 SETTING UP THE EQUIPMENT

1. Ensure that the **delay line patch lead** (white lead with yellow plugs) is disconnected from the delay line and connect the **delay line** to the **TDR200** using the short connecting lead shown in figure 2.2.

Connect the **Reflectometer** to the **PC** via the **USB cable.** The **USB connector** (printer-type) is on the rear panel of the **TDR200 unit.**

Connect the **mains lead** to the mains supply and the rear panel connector and switch on using the front and rear panel **supply on** switches. Operation of the **rear panel switch** charges the battery and lights the **green Charging** LED, while **that on the front panel** switches on the unit and lights the **red Power** LED.

The connection arrangements are shown in figures 2.2.1 and 2.2.2.

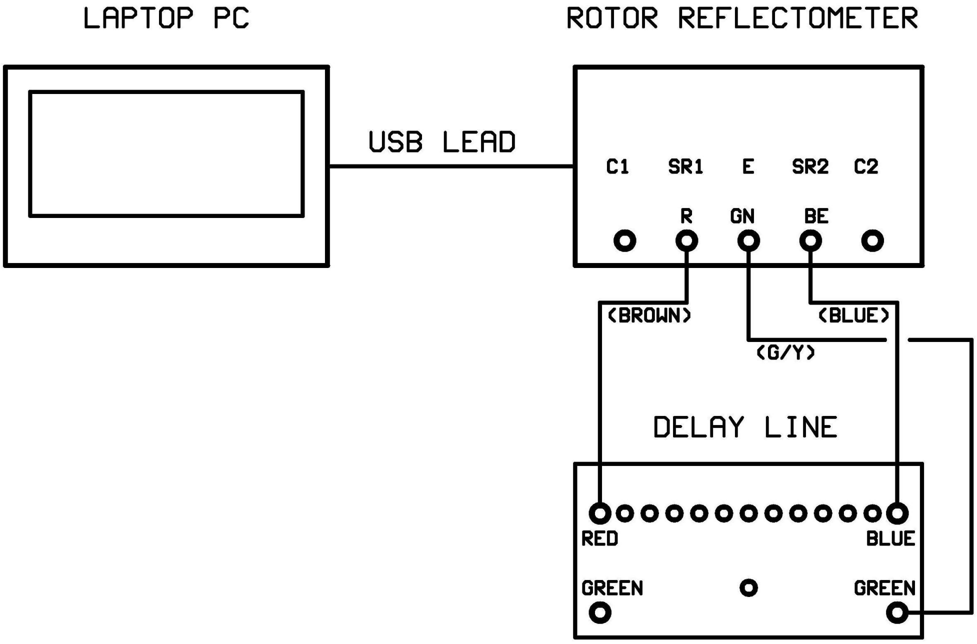


Figure 2.2.1 Connection diagram using delay line

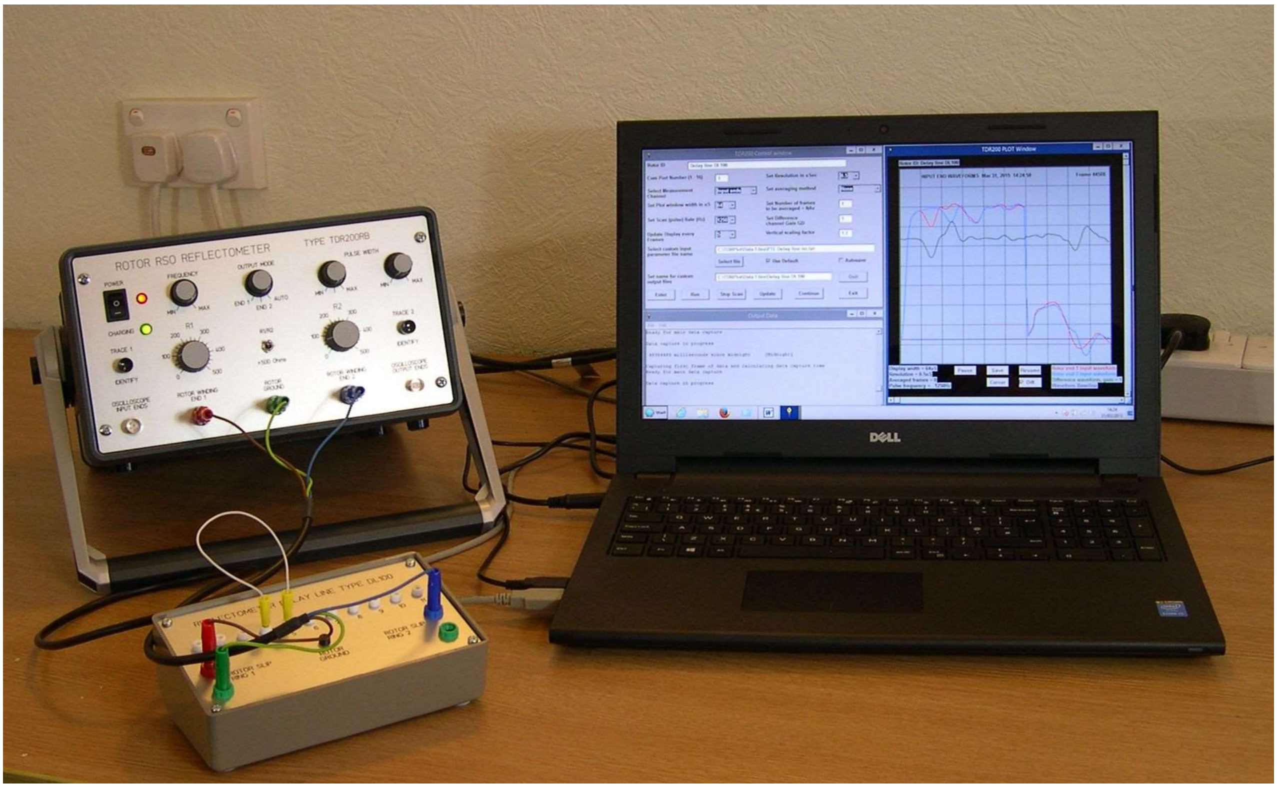
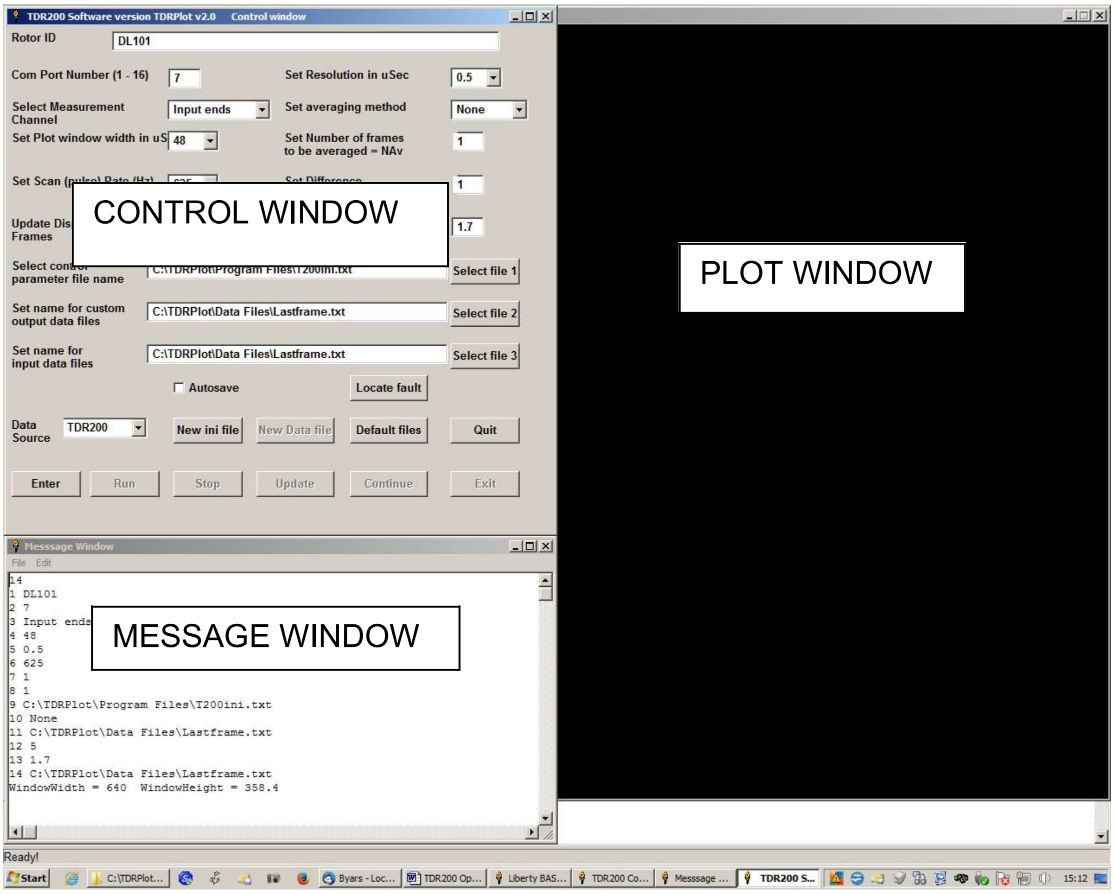


Figure 2.2.2 TDR200 system with DL100 delay line

3. Boot up the PC and run the **TDRPlot** software by clicking on the RT **TDRPlot Desktop icon**. The program will run and the **TDRPlot screen** will open as shown in figure 2.2.3.



Rotor ID: DL101

Com Port Number (1 - 16): 7

Set Resolution in uSec: 0.5

Select Measurement Channel: Input ends

Set averaging method: None

Set Plot window width in uS: 48

Set Number of frames to be averaged = NAv: 1

Set Scan (pulse) Rate (Hz)

Set Difference: 1

Update Dis… Frames

1.7

Select control parameter file name: C:\TDRPlot\Program Files\T200ini.txt

Set name for custom output data files: C:\TDRPlot\Data Files\Lastframe.txt

Set name for input data files: C:\TDRPlot\Data Files\Lastframe.txt

☐ Autosave

Data Source: TDR200

```
14
1 DL101
2 7
3 Input ends
4 48
5 0.5
6 625
7 1
8 1
9 C:\TDRPlot\Program Files\T200ini.txt
10 None
11 C:\TDRPlot\Data Files\Lastframe.txt
12 5
13 1.7
14 C:\TDRPlot\Data Files\Lastframe.txt
WindowWidth = 640  WindowHeight = 358.4
```

Ready!

Figure 2.2.3 Initial TDRPlot screen

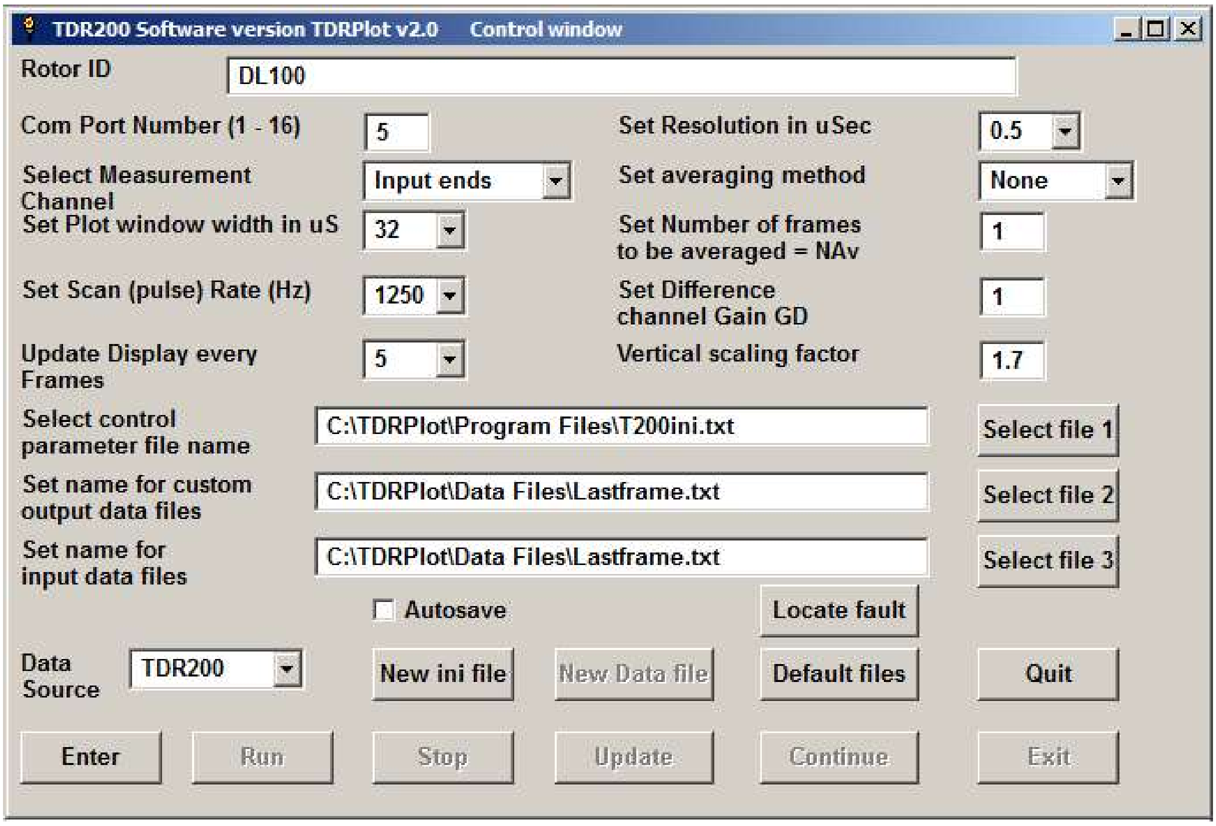
The **TDRPlot screen (**shown in fig. 2.2.3**)** contains 3 windows:

1. A **Control Window** (upper left region of screen).

2. An **Output message window** (below the Control Window).

3. A **Plot window** at the Right Hand Side (RHS) of screen, which is blank at start-up.

The **Control window** at start-up should resemble that shown in figure 2.2.4 below, although some of the parameters at start-up may vary from those shown.



TDR200 Software version TDRPlot v2.0 Control window

Rotor ID: DL100

Com Port Number (1 - 16): 5

Select Measurement Channel: Input ends

Set Plot window width in uS: 32

Set Scan (pulse) Rate (Hz): 1250

Update Display every Frames: 5

Set Resolution in uSec: 0.5

Set averaging method: None

Set Number of frames to be averaged = NAv: 1

Set Difference channel Gain GD: 1

Vertical scaling factor: 1.7

Select control parameter file name: C:\TDRPlot\Program Files\T200ini.txt

Set name for custom output data files: C:\TDRPlot\Data Files\Lastframe.txt

Set name for input data files: C:\TDRPlot\Data Files\Lastframe.txt

☐ Autosave

Data Source: TDR200

Figure 2.2.4 Initial Control Window

2.3 SETTING THE TDR200 FRONT PANEL CONTROLS

Adjust the front panel controls on the **TDR200** unit as follows:

Frequency: Max clockwise

R1 and R2 controls: Set to 100 Ohms

Pulse width switch: middle position

Pulse width control: Fully counterclockwise (minimum)

Output mode switch: Auto

2.4 INITIALISING THE PARAMETERS IN THE CONTROL WINDOW

Set the parameters in the PC **Control Window** as follows:

Rotor ID: Enter the text "DL100 Delay Line"

Com Port Number: The number of the PC com port in use (see **Appendix A1.8**).

Select Measurement Channel: Input ends

Set Plot window width: 48uS

Set scan Rate Hz 1250

Update Display: 5 frames

Set resolution : 0.5uS

Set averaging method: None

Set number of frames to be averaged (NAv): 1

Set difference channel gain (GD): 1

Set Vertical Scaling factor = 1.6

2.5 STARTING DATA CAPTURE

2.5.1 Viewing the RSO waveforms at the input ends

Once the correct parameters have been entered in the **Control window**, click on the **ENTER** button. This loads the set parameters into the **TDRPlot** software.

Next click on the **Run** button, which starts the data capture process. The waveforms at the **input ends** of the delay line (which simulates the rotor winding) will be displayed in the **Plot window** as shown in figure 2.5.1.

Adjust the **Pulse width** controls and also the values of both **R1** and **R2** to approximately 100 Ohms on the **TDR200 front panel** so that the displayed waveforms are similar to those shown in figure 2.5.1.

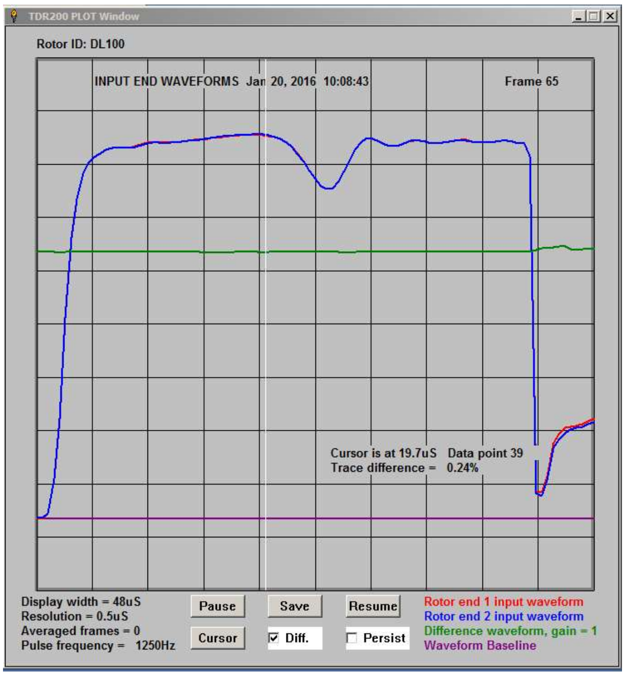
Note that there are 2 identical but superimposed waveforms plotted in **red** (end 1) and **blue** (end 2), corresponding to the pulses injected at each end of the rotor winding. There is also a **green** plot which shows the difference between the plotted waveforms.

To confirm the presence of the 2 superimposed waveforms, push the **Trace 1 identify** button on the front panel of the **TDR200 unit**. The **red** trace for end 1 will be displaced downwards while the button is kept pressed.

Similarly, if the **Trace 2 identify** button is pressed, the **blue** (end 2) waveform will be displaced downwards.

Click on the **Pause button** in the **Plot window**, which will stop the scanning.

Now click the **mouse pointer** at a point near the centre of the waveforms. This will generate a white vertical time **cursor line** as shown in figure 2.5.1.



Rotor ID: DL100

INPUT END WAVEFORMS Jan 20, 2016 10:08:43

Frame 65

Cursor is at 19.7uS Data point 39
Trace difference = 0.24%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

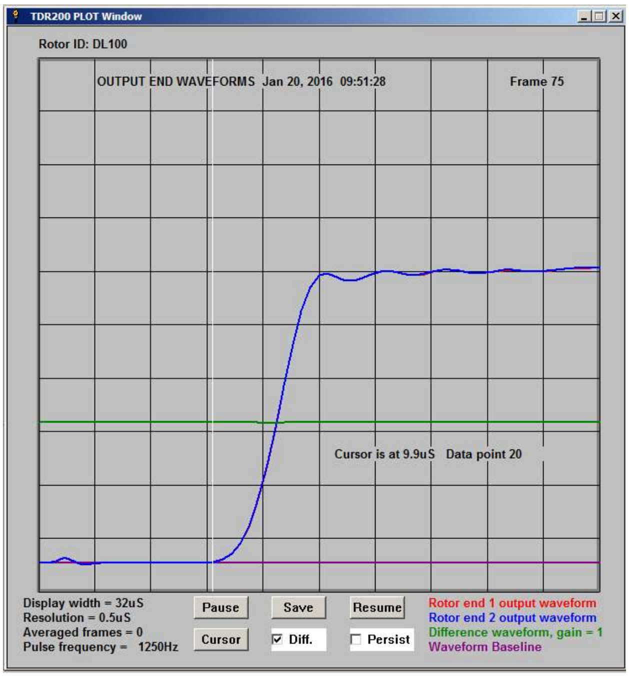
Figure 2.5.1 Input end waveforms for fault-free delay line

Note that there is a major change in the waveforms in figure 2.5.1 after about 20uS. This is caused by an intrinsic change in the characteristic impedance at each end of the demonstration delay line. This effect will not normally be seen when testing an actual rotor.

2.5.2 Viewing the RSO waveforms at the output ends.

Now click again on the **Pause button** and set the **Measurement channel** box in the **Control window** to display the **output end** waveforms.

Set the **Plot window width** to 32uS, then click the **Update** button in the **Control window** and then the **Continue** button to display the **output end** waveforms as shown in figure 2.5.2.



Rotor ID: DL100

OUTPUT END WAVEFORMS Jan 20, 2016 09:51:28

Frame 75

Cursor is at 9.9uS Data point 20

Display width = 32uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 2.5.2 Output end waveforms for fault-free delay line

The **output end** waveforms are zero initially because it takes a finite time, known as the **Single Pass Transit time** (**SPT)** for the leading edge of the applied pulse to reach the end of the simulated rotor winding. This time can be measured using the **Cursor button**.

Click on the **Pause button** in the **Plot window.** Now click the **mouse pointer** at the start of the leading edge of the output pulses as shown in figure 2.5.2, where the transit time (SPT) is measured as 9.9uS.

2.6 SETTING THE MATCHING CONTROLS R1 AND R2

The **impedance matching controls R1 and R2** have a major effect on the displayed waveforms. However, the effects are identical for both sets of RSO waveforms and it is impossible to obtain different waveforms for each half-winding of a fault-free rotor winding by incorrect setting of these controls. The correct values of R1 and R2 for use with the delay line are approximately **100** Ohms. However, for a rotor winding, this value will be unknown initially and must be measured as described below.

2.6.1. EFFECTS OF THE VALUE OF R1

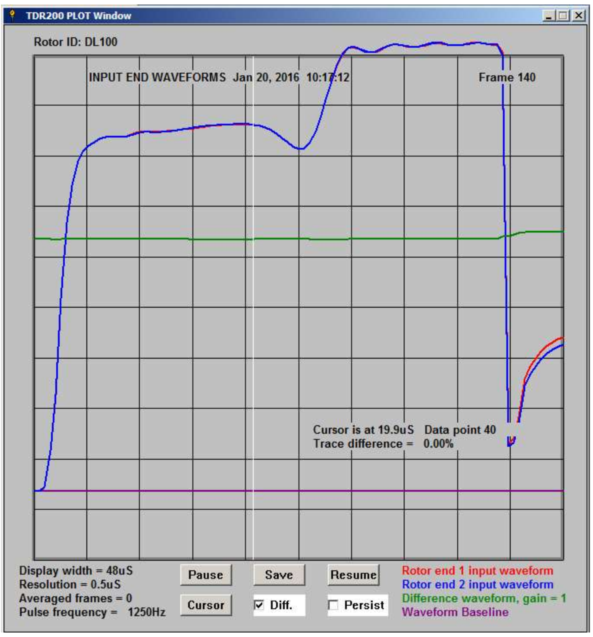
The visual effect of adjusting R1 is primarily to adjust the amplitudes of the displayed RSO waveforms. In practice, R1 is normally set to the same value as R2, once the correct value for R2 has been found, as described in section 2.6.2.

2.6.2 SETTING THE VALUE OF R2

On the front panel of the **TDR200** unit, set the values of **R1** and **R2** = 100 ohms and disconnect the **delay line patch lead (**yellow plugs**)**.

Set the **Plot window width** back to 48uS, then click the **Update** button in the **Control window** and then the **Continue** button to resume scanning.

Now set the value of **R2** to **200** Ohms. The displayed waveforms should appear as shown in figure 2.6.1 below. Notice that the amplitude of the pulse waveform increases after approximately 20uS (twice the single-pass transit time) because of the reflection at the mismatched impedance at the end of the delay line.



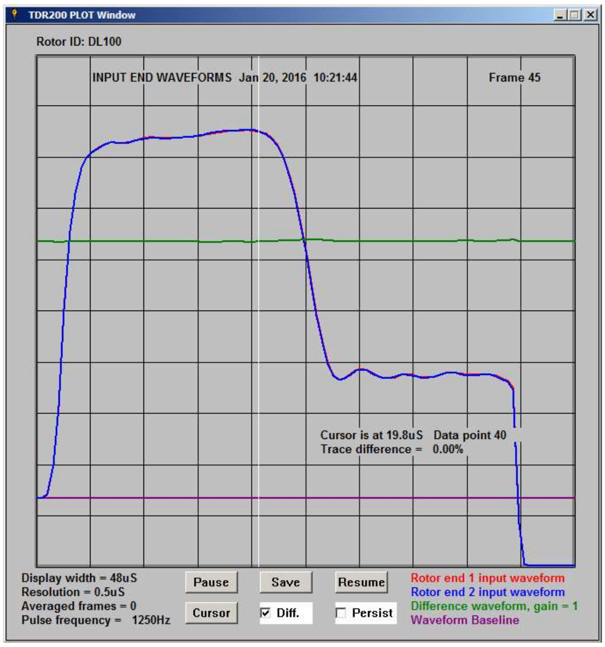
Rotor ID: DL100

Cursor is at 19.9uS Data point 40
Trace difference = 0.00%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 2.6.1 Input end waveforms with R1 = 100 Ohms and R2 = 200 Ohms

Now set the value of **R2** to zero and resume scanning.



TDR200 PLOT Window

Rotor ID: DL100

INPUT END WAVEFORMS Jan 20, 2016 10:21:44

Frame 45

Cursor is at 19.8uS Data point 40
Trace difference = 0.00%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

☑ Diff.
☐ Persist

Figure 2.6.2 Input end waveforms with R1 = 100 Ohms and R2 = 0 Ohms

Now the reflected pulse becomes negative and causes the amplitude of the RSO waveform to decrease after approximately 20uS.

The time from the start of the injected pulse to the point at which the waveforms change when R2 is varied is known as the **Double-Pass Transit time** (DPT) and is the time taken for the pulse to travel from one end of the winding and back again when the terminating impedance R2 is incorrect.

The correct value for R2 (and hence R1) is the value which causes no net reflection at the output ends of the rotor winding, so that the waveforms are similar to those shown in figure 2.5.1.

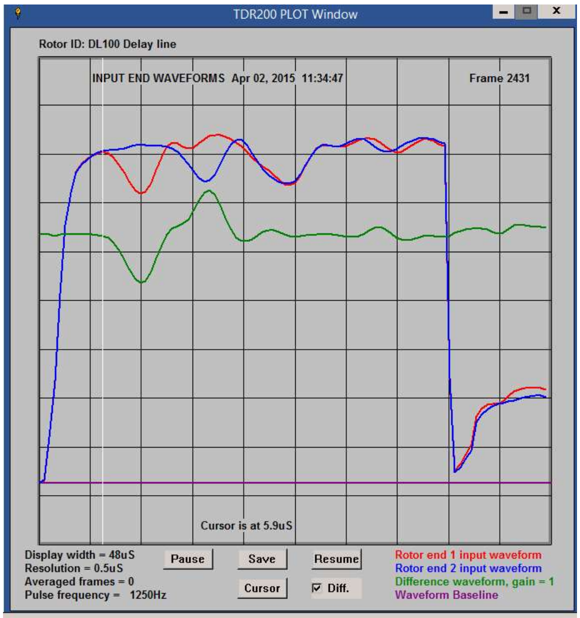
2.7 DEMONSTRATING WINDING FAULTS WITH THE DL100 DELAY LINE

Revert to monitoring the **input end** waveforms by setting the **Measurement channel** box in the **Control window** to display the **input end** waveforms, then click the **Update** button and then the the **Continue** button to resume scanning.

Some sample waveforms obtained using the **TDRPlot software** for a simulated inter-coil and earth fault are given in the next two figures.

2.7.1 Simulated inter-coil fault

Apply a simulated inter-coil fault by connecting the delay line patch lead between terminals 4 and 5 on the delay line. Figure 2.7.1 shows the resulting waveforms.



Rotor ID: DL100 Delay line

INPUT END WAVEFORMS Apr 02, 2015 11:34:47

Frame 2431

Cursor is at 5.9uS

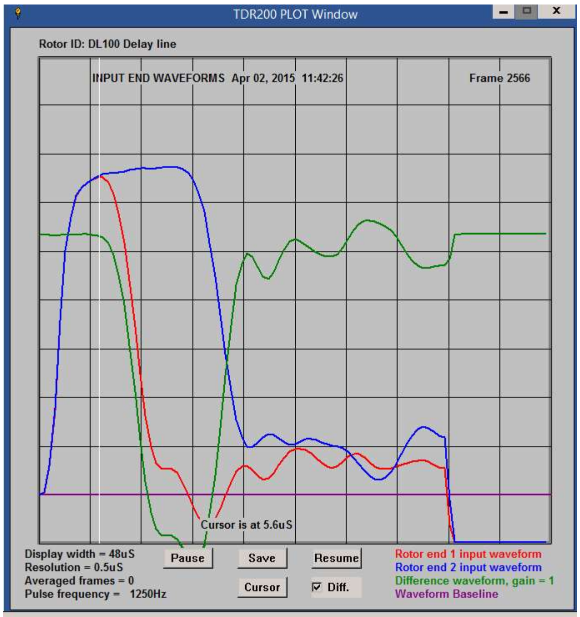
Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 2.7.1. Input and difference waveforms for a short between terminals 4 and 5

By locating the cursor at the point where the waveforms start to diverge and comparing the cursor time with the single-pass transit time, the approximate fault location can be deduced. Note that the green difference trace is no longer a horizontal line.

2.7.2 Simulated earth fault

Apply a simulated earth fault by connecting the **delay line patch lead** between terminal 4 and the **black Rotor Ground terminal** on the **delay line**. Figure 2.7.2 shows the resulting waveforms.



Rotor ID: DL100 Delay line

INPUT END WAVEFORMS Apr 02, 2015 11:42:26

Frame 2566

Cursor is at 5.6uS

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 2.7.2

Input and difference waveforms for a short between terminal 4 and ground

Note that it is possible to turn the **Difference** waveform on and off by checking or unchecking the **Diff checkbox** after the **Pause** button has been clicked.

The **waveforms for a real rotor winding** with winding faults will normally show **much less difference** between the traces for each end under fault conditions.

2.8 INTERPRETING THE WAVEFORMS

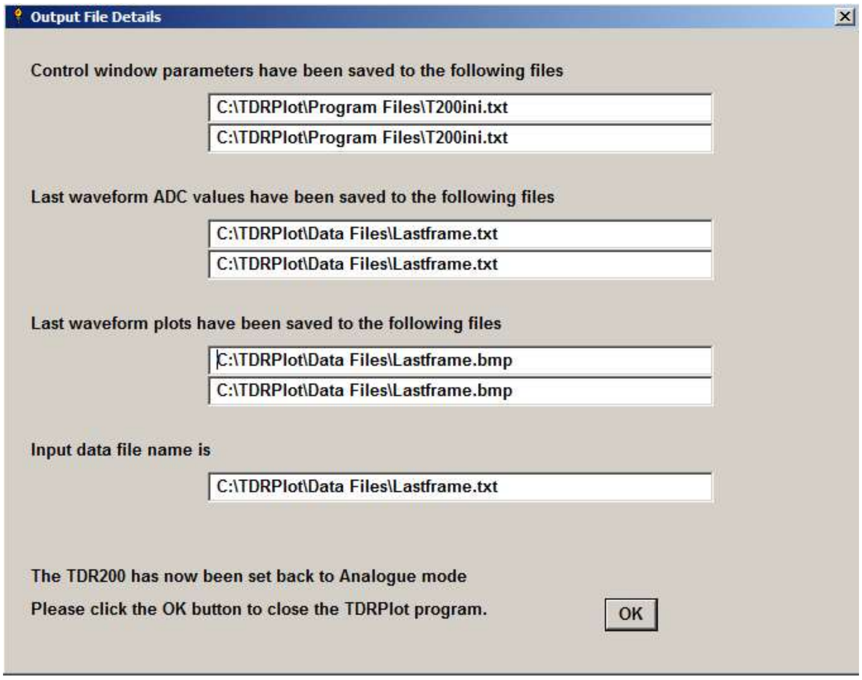
A **normal fault-free rotor winding** is characterised by **2 identical waveforms** at each end of the rotor winding (red and blue waveforms) with a horizontal straight line (green) difference waveform, as shown in figure 2.5.1.

Detailed information about how to interpret the **RSO waveforms** is given later in section **11** and also sections 12 and 14 of the **Reference Manual**.

2.9 EXITING THE SOFTWARE

After scanning has started, press the **EXIT** button in the **Control** window to terminate the program.

This generates a number of files containing the last frame of ADC data and also a copy of the **Plot window** in bitmap format as described in **section 8**. An **Output File Details window** is also generated as shown in figure 2.9.1.



Control window parameters have been saved to the following files

C:\TDRPlot\Program Files\T200ini.txt

C:\TDRPlot\Program Files\T200ini.txt

Last waveform ADC values have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.txt

C:\TDRPlot\Data Files\Lastframe.txt

Last waveform plots have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.bmp

C:\TDRPlot\Data Files\Lastframe.bmp

Input data file name is

C:\TDRPlot\Data Files\Lastframe.txt

The TDR200 has now been set back to Analogue mode

Please click the OK button to close the TDRPlot program.

Figure 2.9.1 Output File Details window

Note that to exit the software before scanning has started, click on the **QUIT** button in the **Control window**. In this case, no new data files will be generated.

2.10 OUTPUT FILE MANAGEMENT

The **output data files** generated by the **TDRPlot** software will be in the **Data Files** subfolder in the **Default** folder (see **section 8** for more information)..

Once a test has been completed, we suggest that **a new folder** should be created with a unique name which identifies the rotor under test.

The files in the **Data Files** subfolder should then be moved to this new folder for safe keeping.

2.11 THE NEXT STEPS

This concludes the **Quickstart** section **in digital mode**.

Detailed information about the **RSO test** and practical advice on using this test method on real rotor windings can be found in a number of technical papers included in the supplied **software and documentation CD.**

Further information about using the **TDRPlot** software with **real rotor windings** is given in sections **9-14**.

The remaining sections of this manual give additional information about the **TDRPlot** software. These sections contain some repetition of previous sections to help new users acquire experience and confidence in the use of the software.

3. QUICKSTART INSTRUCTIONS (ANALOGUE MODE)

3.1 OVERVIEW

Although the **TDR200** system is designed to be operated in **Digital mode** with a **Control PC**, it can also be used in an **analogue mode** with an **oscilloscope** if required.

This second **Quickstart section** decribes and demonstrates the operation of the **TDR100** unit in **analogue mode** to display the RSO waveforms on an oscilloscope screen using the supplied **DL100 delay line**. Detailed instructions for using the equipment with actual rotor windings can be found in later sections.

In its **analogue** mode of operation, the **TDR200** applies rectangular pulses to each end of the rotor winding alternately via an electronic switching network. The resulting **input** or **output end** waveforms are displayed on the channels of an oscilloscope as 2 alternating waveforms. Because the switching network operates at a relatively high speed (around 500Hz), these appear as 2 superimposed waveforms on the oscilloscope screen, allowing any differences between these waveforms to be viewed directly.

The pulse repetition rate is set by the **Frequency** control on the Reflectometer front panel and the width of the applied pulse is set by a pair of **Pulse Width** controls.

3.2 THE DEMONSTRATION DELAY LINE

Details of the **DL100 delay line**, are given in in section 2.1 of this manual and in more detail in **section 5** of the **TDR200 Reference Manual)**.

Please note that the delay line is supplied for demonstration and checking purposes only. It is not required when testing a real rotor winding.

In use, the **Delay line** is connected to the **Reflectometer** as previously described in section 2.1.

3.3 SETTING UP THE EQUIPMENT

The following instructions assume the use of a **conventional analogue oscilloscope**. Information and advice on the use of **digital oscilloscopes** is given later in section 12.5.

1. Connect the **delay line** to the **TDR200** unit as described in section 2.1, using the short connecting lead shown in figure 2.1.2. Ensure that the **delay line patch lead** (white lead with yellow plugs) is disconnected from the delay line terminals.

2. Connect the **Reflectometer** to the **oscilloscope** input terminals using the coaxial leads supplied.

3. Connect the mains lead to the mains supply and the rear panel connector and switch on using the front and rear panel supply on switches.

Note that operation of the rear panel switch charges the internal battery and lights the green Charging LED, while that on the front panel switches on the unit and lights the red Power LED.

The connection arrangements are shown in figures 3.3.1 and 3.3.2.

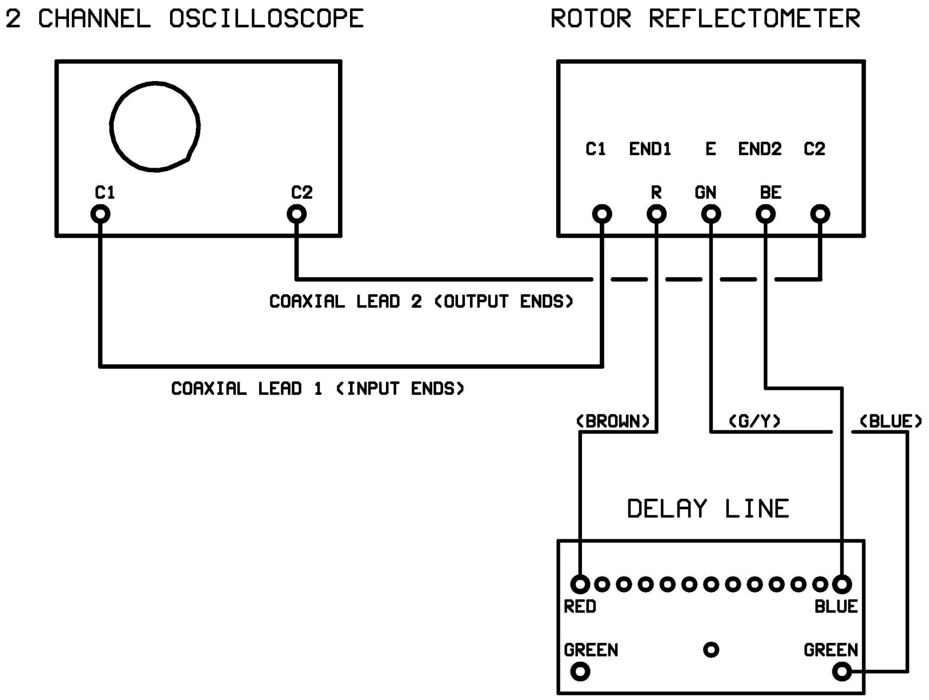


Figure 3.3.1 Connection diagram using delay line

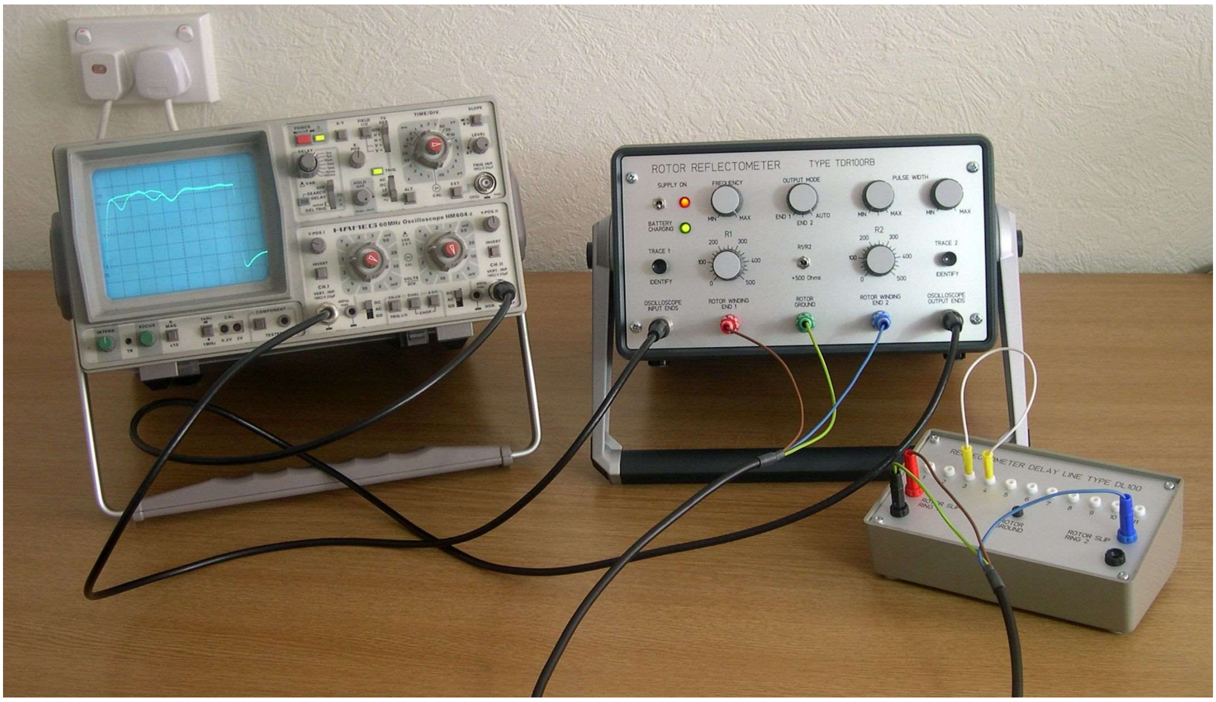


Figure 3.3.2 Physical realisation of figure 3.3.1

3.3.1 SETTING THE TDR200 FRONT PANEL CONTROLS

Set the controls on the **Reflectometer** initially as follows:

R1= R2 = :100Ω
PULSE FREQUENCY : Fully clockwise
PULSE WIDTH SWITCH : Centre position
PULSE WIDTH POTENTIOMETER : Mid scale
OUTPUT MODE SWITCH : Auto
R1/R2 TOGGLE SWITCH : Up (0 - 500 Ohms)

3.3.2 SETTING THE OSCILLOSCOPE CONTROLS

For reasons explained later, best results will be obtained using a conventional analogue oscilloscope, as this allows each pair of RSO waveforms to be displayed and viewed in real time. In this case, a simple digital camera can be used to capture the screen shots for permanent records.

Set the oscilloscope controls initially as follows:

DISPLAY : Channel 1
VERTICAL SENSITIVITY : 1V/CM (Both channels)
TRIGGER CONTROLS
- MODE : Normal
- SOURCE : Channel 1
- LEVEL : Positive
- SLOPE : Positive
- COUPLING : D.C.
- TIME BASE : 5 μsec/division

3.4 TYPICAL OSCILLOSCOPE WAVEFORMS UNDER MATCHED CONDITIONS

3.4.1 Input end waveforms

With the oscilloscope set to **Channel 1** to monitor the input ends of the delay line, adjust the pulse width so that the display resembles that shown in Fig. 3.4.1(a). Under these conditions, R1 and R2 match the characteristic impedance of the delay line and the pulses pass through the delay line and are absorbed without reflection in R2. The sharp waveform dip is caused by a deliberate impedance mismatch at the ends of the delay line.

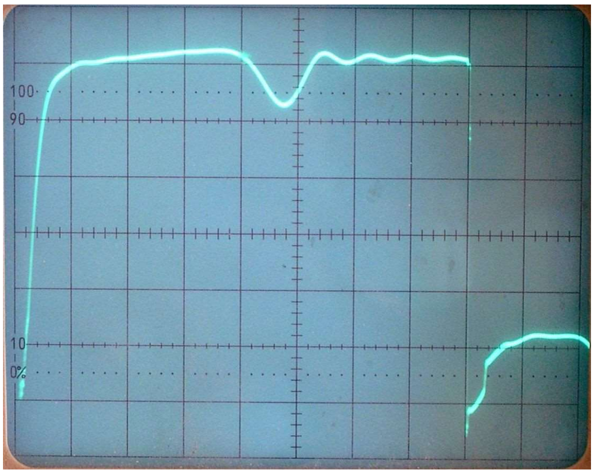


Figure 3.4.1 (a) Input ends waveforms with R1 = R2 = 100 Ohms

3.4. 2 Output end waveforms

Now set the oscilloscope to monitor the output ends of the delay line (**Channel 2**) and set the time base to 2 uS/division. Ensure that the triggering remains set to the input ends signals (**Channel 1**) and R1 = R2 = 100 Ohms. The output end waveforms should now appear as shown in figure 0.5(b).

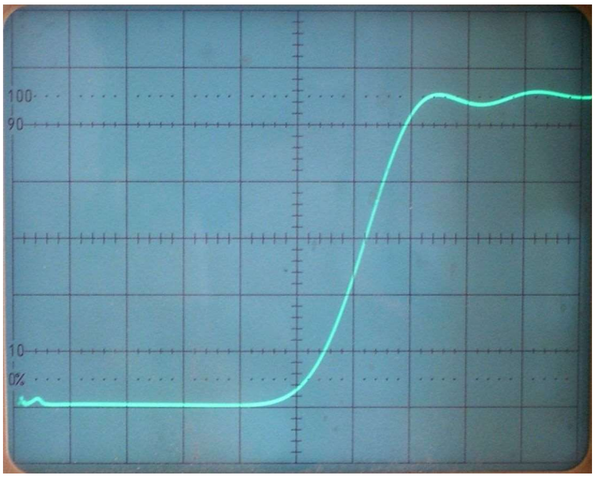


Figure 3.4.1 (b) Output ends waveforms with R1 and R2 = 100 Ohms

Figure 3.4.1(b) shows that no signal is received at the far end of the delay line until a time delay of approximately 10uS (5 divisions). This delay time is known as the single-pass transit time. The slow risetime of the output waveform is a characteristic of the delay line itself and not the **TDR200** unit.

3.5 ADJUSTING THE IMPEDANCE MATCHING CONTROLS R1 AND R2

The **impedance matching controls R1 and R2** have a major effect on the displayed waveforms. However, the effects are identical for both sets of RSO waveforms and it is impossible to obtain different waveforms for each half-winding of a fault-free rotor winding by incorrect setting of these controls. The correct values of R1 and R2 for use with the delay line are approximately 100 Ohms. However, for a real rotor winding, this value will be unknown initially and must be measured as described later.

3.5.1. CHANGING THE VALUE OF R1

The effect of adjusting R1 is primarily to adjust the amplitudes of the displayed RSO waveforms. In practice, R1 is normally set to the same value as R2, once the correct value for R2 has been found, as described below.

3.5.2. CHANGING THE VALUE OF R2

The effect of mismatching the value of the output end terminating resistor R2 can be demonstrated by changing the setting of R2 on the Reflectometer.

When R2 is set to zero, the output pulses are reflected back to the input ends of the delay line with opposite polarity, so that the pulse amplitude monitored at the input end of the winding becomes zero after a time delay which allows the pulses to pass through the delay line and back again. This delay time is known as the double-pass transit time.

Fig. 3.5.1 shows the input end waveforms when R2=0. The double pass transit time is seen to be approximately 20μS (4 divisions).

Figure 3.5.1 Input ends waveforms with R1 = 100 Ohms and R2 = 0 Ohms

Now slowly increase the value af R2 from 0 to 100 Ohms, and note that the reflected pulse amplitude is reduced and becomes zero when R2 = 100 Ohms, as shown in figure 3.4.1(a).

Similarly, when the value of R2 is set to a value large than that of the delay line characteristic impedance, partial reflection of the the pulses again occurs, but now they are reflected back to the input ends of the delay line with positive polarity. The pulse amplitude monitored at the input end of the winding therefore increases after the double-pass transit time. A typical example is shown in Fig. 3.5.2, which shows the input-end waveforms obtained with R2 set to 150 Ohms.

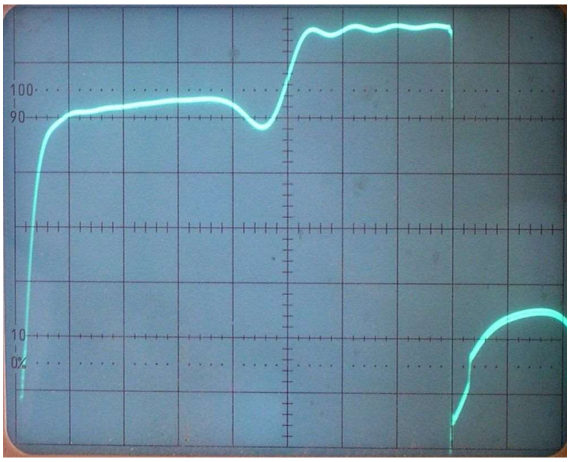


Figure 3.5.2 Input ends waveforms with R1 = 100 Ohms and R2 = 150 Ohms

3.5.3. SETTING THE OPTIMUM VALUES FOR R1 AND R2

The optimum value for R2 (and hence R1) is that which causes no net reflection at the output ends of the rotor winding, so that the waveforms are similar to those shown in figure 3.4.1(a). Setting R1 and R2 to these values ensures that all tests are carried out under repeatable conditions and minimizes the effect on the waveforms caused by multiple pulse reflections at each end of the delay line or rotor winding.

3.5.4 CHECKING FOR 2 WAVEFORMS USING TRACE IDENTIFY BUTTONS

In all of the examples listed to-date, the oscilloscope has displayed 2 superimposed waveforms. To conform this, push in each of the **trace identify** buttons in turn, which connects a high value resistor across the selected winding end. This allows the individual waveforms at each end of the winding to be identified.

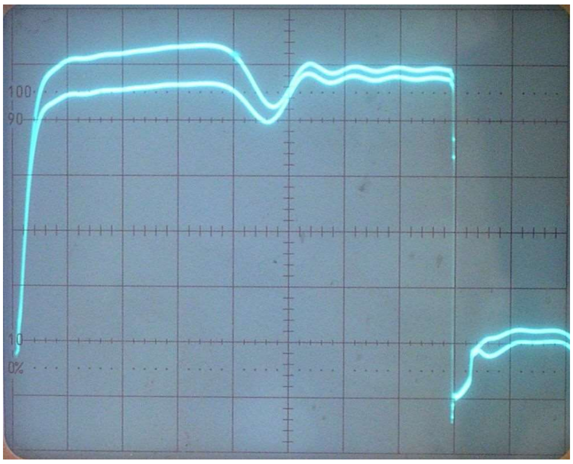


Figure 3.5.3 Operation of trace identification buttons

3.6 DEMONSTRATING WINDING FAULTS WITH THE DL100 DELAY LINE

3.6.1 Simulated inter-coil fault

The effect of a **shorted turn or coil** can be demonstrated by shorting out one or more delay line sections. Figure 3.6.1 shows the **RSO input end waveforms** when the patch lead is connected between terminals 4 and 5 on the delay line. The approximate fault location can be estimated by comparing the time at which the waveforms start to diverge with the double-pass transit time.

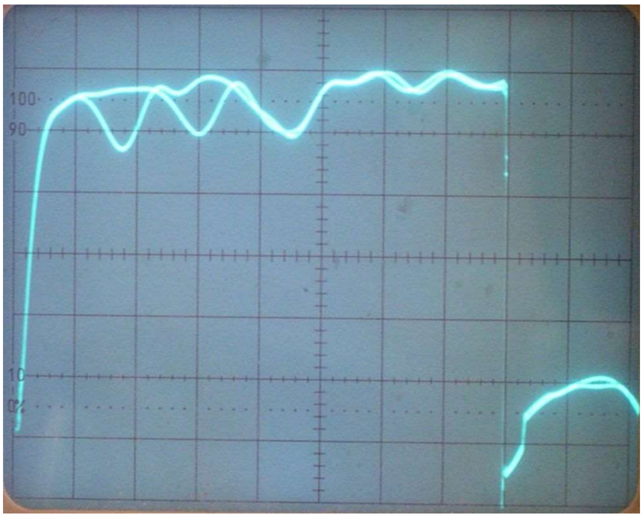


Figure 3.6.1 Short applied between terminals 4 and 5 on delay line

Note that a single shorted turn on a real rotor winding will give a much smaller difference between the input end waveforms than shown above.

3.6.2 Simulated earth fault

The effect of a simulated earth fault may be demonstrated by shorting one of the delay line junctions to earth using the 2mm plug lead supplied. Fig. 3.6.2 (a) shows the result of shorting junction 4 to earth.

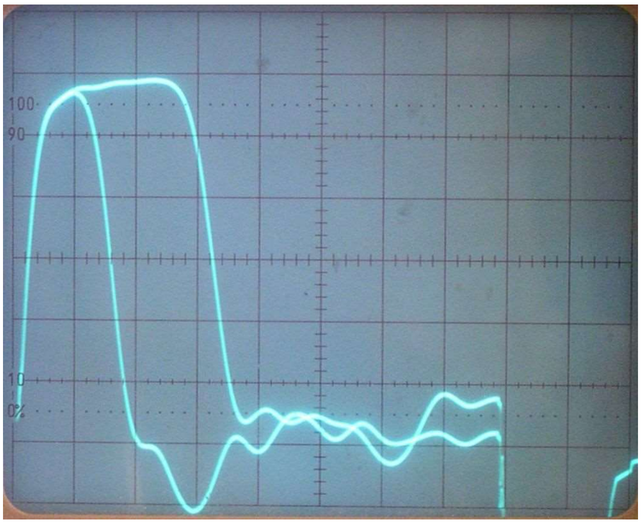


Figure 3.6.2 Short applied between terminals 4 and ground on delay line

3.7 INTERPRETING THE WAVEFORMS

A **normal fault-free rotor winding** is characterised by **2 identical waveforms** at each end of the rotor winding. Further information is given in **section 12 of the TDR200 Reference manual**.

3.8 THE NEXT STEPS

This concludes the **Quickstart** section for operation in **analogue** mode.

Detailed information about the **RSO test** and practical advice on using this test method on real rotor windings can be found in the remaining sections of this manual and also in a number of technical papers included in the supplied **documentation CD**.

4. THE TDR200 ROTOR REFLECTOMETER MEASUREMENT SYSTEM

4.1 OVERVIEW

The **principle of operation** of the **TDR200 RSO Rotor Reflectometer** has been described in previous sections. This section gives more detailed information about its operation.

1. In **Digital mode** the RSO waveforms are controlled by and displayed on a **Control PC** where they can be saved as either **bit-map images** or as **text files**. This is the **default mode** of operation.

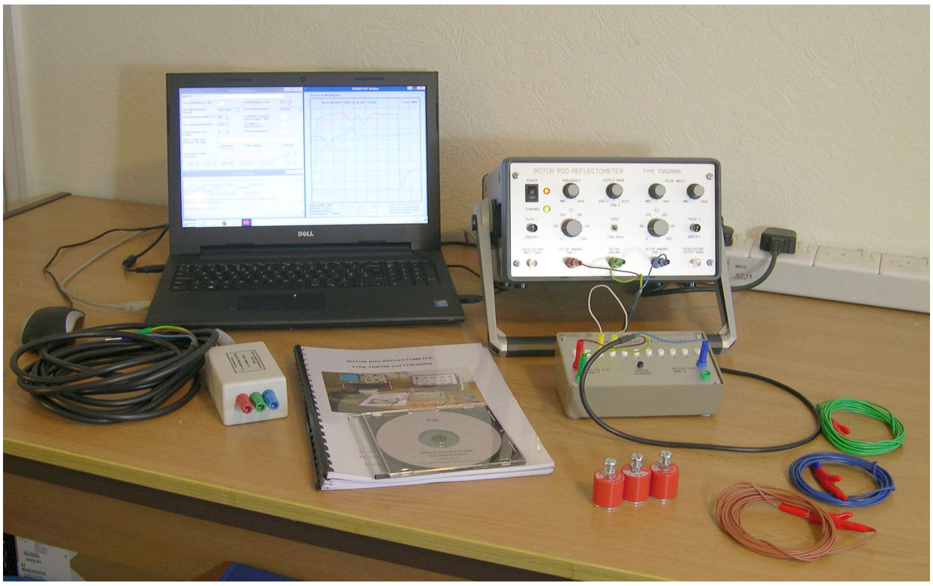


Figure 4.1(a) The TDR200 RSO Rotor Reflectometer measurement system in digital mode

2. In **Analogue mode**, the RSO waveforms are displayed on an **oscilloscope** (not supplied)**.**

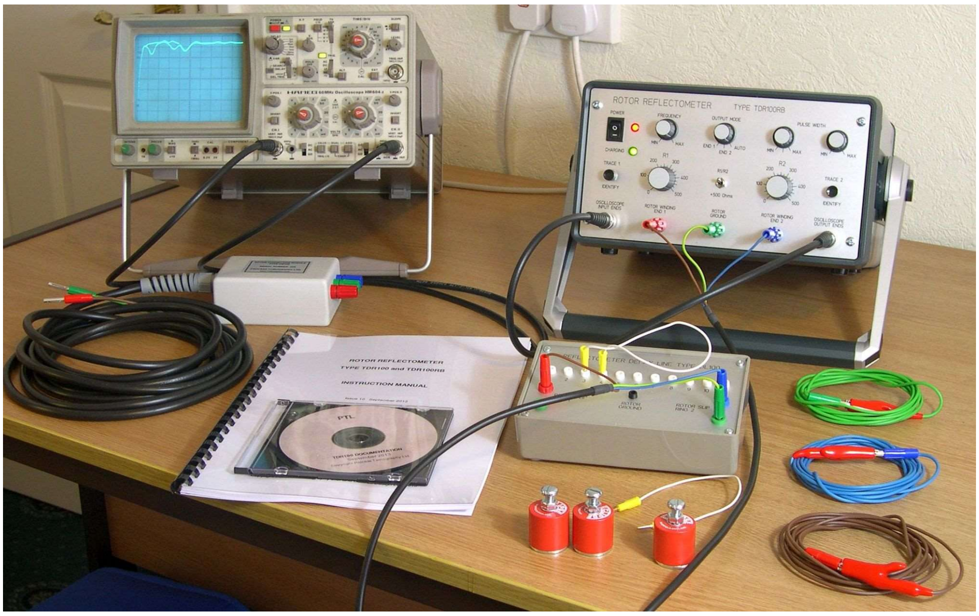


Figure 4.1(b) The TDR200 RSO Rotor Reflectometer measurement system in analogue mode

In both operating modes, the **RSO waveforms at each end** of the rotor winding can be displayed **continuously and** (almost) **simultaneously**, which permits winding faults to be identified quickly and unambiguously.

The operation of the equipment can be demonstrated with **simulated inter-turn and ground faults** applied to a **demonstration delay line,** which is supplied with the equipment. **This item is not used for real rotor measurements**.

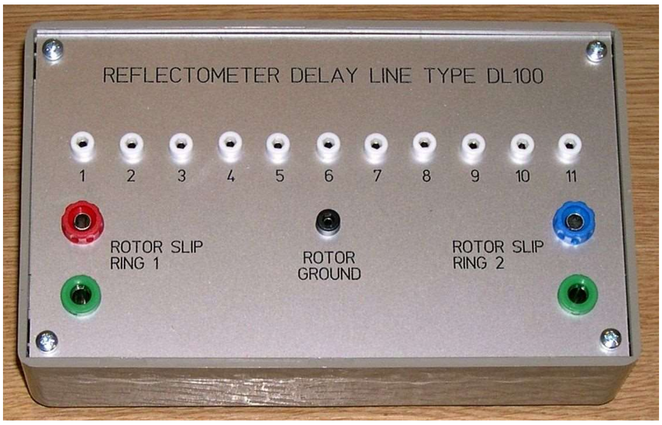
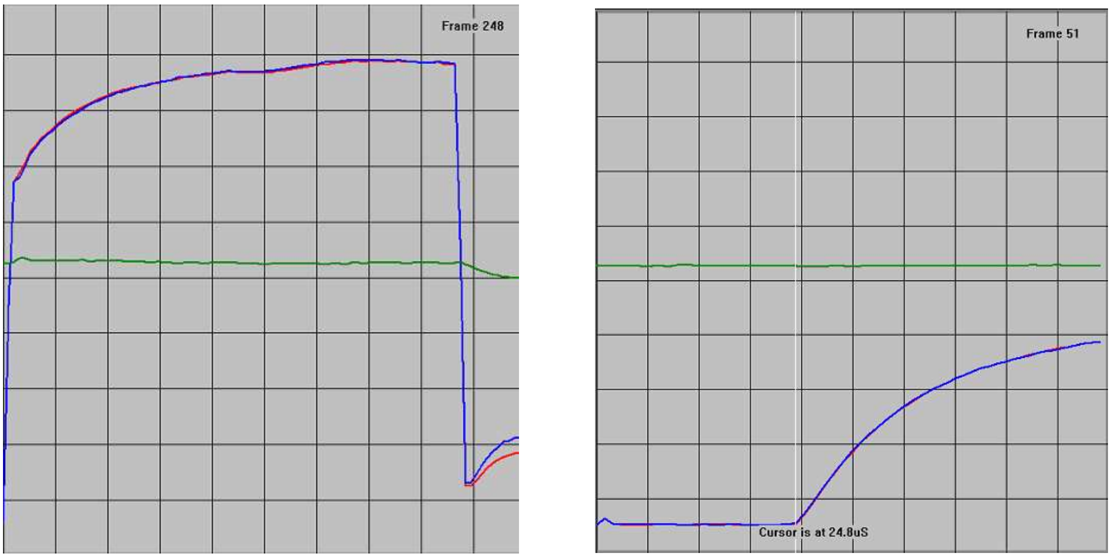


Figure 4.1(c) The DL100 Delay line.

The RSO waveforms at the **input ends** of the winding (figure 4.1.2a) below. are used to measure the **characteristic impedance Z0** of the rotor winding and to **detect** and **locate winding faults**.

The waveforms at the **output ends** of the winding (figure 4.1.2b) are used to measure **the time taken for the RSO pulse to travel through the rotor winding from the input to the output ends** (the **single-pass transit time**). Knowledge of this time is required to allow winding faults to be located.



(a) Input ends **(b) Output ends**

Figure 4.1.2 RSO waveforms at input and output ends of fault-free winding in digital mode

4.1.2 TDR200 OUTPUT MODE CONTROL

The **TDR200** unit can output the **RSO pulses** in one of **3 modes**, controlled by the 3-way **Output Mode switch** as follows:

Position '**END1**' - Pulses are injected into slip ring 1 only.

Position '**END**2' - Pulses are injected into slip ring 2 only.

Position '**AUTO**' - Normal operating mode.

Auto mode is normally used in both analogue and digital operating regimes.

However, the other 2 modes allow pulses to be applied to either slip ring 1 or slip ring 2 only. These options can be useful when using a digital oscilloscope to monitor the traces in **analogue mode**, as described in **section 12.5**.

NOTES

1. Mode switch in Digital Mode operation.

For normal rotor testing in **Digital Mode**, the **mode switch** must be set to the '**AUTO**' position, as the **TDRPlot** software will not run in the other 2 modes.

When operating in the '**AUTO**' position the '**Trace Identify**' buttons should always be used to check that two traces are present.

2 . Mode switch in Analogue Mode operation.

The normal position for the **mode switch** in **analogue mode** is also '**AUTO**'.

If only one trace is shown when the **Trace ID** button is pressed, the **triggering** of the oscilloscope (particularly when using a **digital oscilloscope**) should be checked and adjusted until the second trace is also displayed.

However, if this is not possible when a **digital oscilloscope** is used, it may be necessary to use the alternative **End1/2** options in turn, as decribed in **section 12.5**.

4.2 MEASURING THE ROTOR PARAMETERS

In sections 2 and 3 we described how the operation of the **TDR200** system can be demonstrated using a **delay line**. In this case, the c**haracteristic wave impedance Z0** and **transit time** (**t1**) of **the delay line** are known, so the values of **R1, R2** and the **RSO pulse width** can be set directly.

In the case of a real rotor winding **tested for the first time,** these parameters will be unknown quantities and must be measured. Once these are known, the **TDR200** and its **TDRPlot control software** can be set up and optimised.

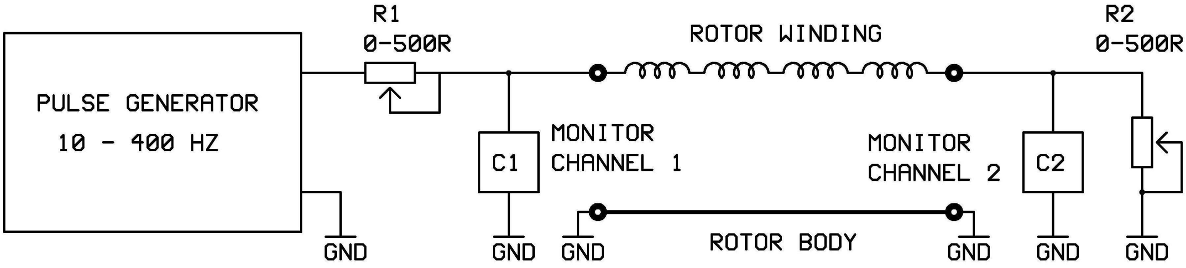


Figure 4.2.1 Basic RSO measurement circuit

The **TDR200 system** is set up as follows:

The values of the pair of adjustable **input and terminating impedance matching resistors** (**R1** and **R2**) are first set to approximately match the **characteristic (wave) impedance** (**Z0**) of the rotor winding as described in **section 4.3**. This is done by monitoring the **RSO waveforms** at the **input ends** of the winding.

The single pass transit time (**SPT**) is next found by observing the **RSO waveforms** at the **output ends** of the rotor winding as described in **section 4.4**.

The **width** of the applied **RSO pulse** is then set to be greater than **2 x the single-pass transit time** by adjusting the **Pulse width controls** on the front panel of the reflectometer and the **Plot window width setting in the TDRPlot software Control window.**

This method of setting up the RSO measurement system ensures that rotor windings are tested under **repeatable conditions** and so allows measurements carried out on the **same rotor at different times** or on **similar rotors** to be easily compared. It also minimizes pulse distortion caused by multiple reflections within the winding.

If the rotor winding is fault-free, **two perfectly superimposed traces** will be displayed. If this occurs **(and the existence of 2 traces is confirmed by use of the Trace ID buttons, see below**) then the rotor winding can be safely assumed to be fault-free. It is important to always check that **2 identical superimposed waveforms** are displayed by depressing one of the **trace identifier buttons** on the **Reflectometer front panel**. This displaces one of the traces **vertically downwards** to confirm the existence of two separate waveforms as shown in **figure 3.5.3.**

If two perfectly superimposed traces are not obtained, there may be a fault in the rotor winding. **Sections 1.5** and **11.8** explain in detail the waveforms to be expected for various types of faults. Note that In normal use, it is almost impossible to incorrectly set the **TDR200 hardware and software controls** so that **two non-identical RSO waveforms are displayed**

The following sections describe in detail how the Rotor winding single-pass transit time and Characteristic wave impedance Z0 can be measured. **Operation in digital mode** has been assumed, but where there are major differences, the alternative instructions for use in **analogue mode** have also been given. In this case, references to "PC screen" should be replaced by "Oscilloscope screen"

Sections 9 onwards give more detailed and practical information about testing real rotor windings and more detailed information about measuring the parameters of an unknown rotor winding is given in section 11.

4.3 MEASURING THE ROTOR CHARACTERISTIC IMPEDANCE (Z0)

The approximate **rotor characteristic impedance** value can be measured as follows

The basic idea is to set the value of **R1** so that the **height of the RSO pulse at the start of the waveform** monitored at the **input ends** is approximately half its height when **R1** is set to zero. In this case, the value of **R1** will equal (approximately) the **characteristic impedance of the rotor winding Z0**.

The controls on **the TDR200** unit should be set as follows:

Pulse width switch: minimum

Pulse width potentiometer: maximum (fully clockwise)

On the **PC screen**, set the **Control window Measurement Channel** to monitor the **Input ends** of the winding.

With the **Vertical scaling factor** in the **Control window** set to a value of **1.6**, adjust the **R1** (input impedance) control on the **TDR200 front panel** so that the pulse displayed in the **Plot window** is approximately 80% of the **Plot window height**, as shown in figure 4.3.1. Set **R2** to the same value as **R1**

Note: **In analogue mode**, set the **pulse frequency to maximum** and adjust **R1** so that the **pulse height** is approximately half its height when **R1 = 0.**

In both **modes,** this value of **R1** is the approximate **characteristic impedance of the rotor winding** in Ohms. **Now set R2 to this same value.**

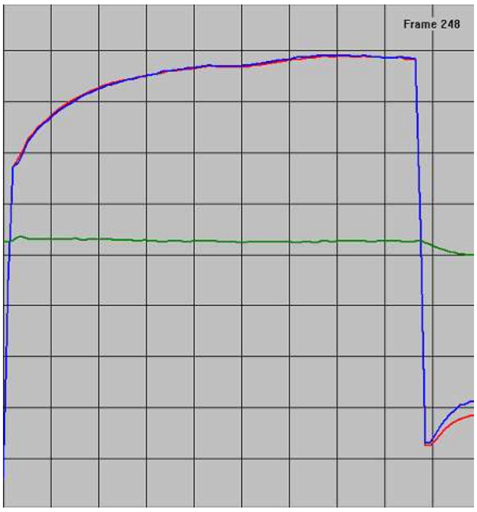


Figure 4.3.1 RSO input end waveforms with R1 adjusted correctly

In figure 4.3.1 there are 2 perfectly superimposed red and blue waveforms. The green horizontal waveform plots the difference between these 2 waveforms.

4.4 MEASURING THE SINGLE-PASS TRANSIT TIME.

The next step is to measure the single-pass transit time (SPT) so that the **pulse width control settings** can be optimised,

On the **PC**, set the **Control window Measurement Channel** to monitor the **Output ends** of the winding.

Adjust the **Control panel Plot window width** and also the **Pulse width controls** on the front panel of the **TDR200** unit until a waveform similar to that shown in figure 4.4.1 is obtained.

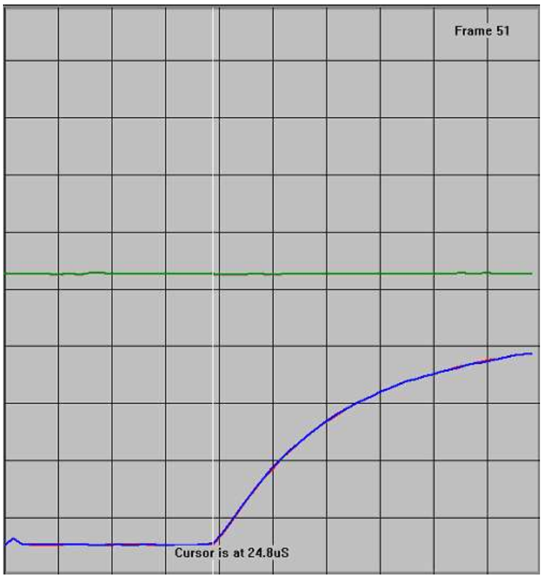


Figure 4.4.1 RSO waveform at output ends

Click on the **Pause button** in the **Plot window**, which will stop the scanning. Now click the **mouse pointer** at the point near the start of the output waveforms (where the waveform starts to increase).

This will generate a white time cursor line as shown in figure 4.4.1 and the **time at the cursor position** will be displayed.

Note the time displayed for the cursor (in this case, 24.8uS). This is the time in microseconds for the pulse to pass through the rotor winding from one end to the other and is known as the **Single-pass transit time** (**SPT**).

Note: In analogue mode, use the **oscilloscope time base controls** to measure the **SPT**.

4.5. OPTIMISING THE VALUE OF R2.

The final step is to measure and set the correct value for the terminating impedance **R2**. This should be similar to that of the input impedance, **R1**. However, it is possible to measure it more accurately as described next.

Reset the **Control window Measurement Channel** to monitor the **Input ends** of the winding.

Set the **Display width** in the **Plot window** to be approximately 2 x **SPT** + 16 uS. So in the above case, where SPT is 24.8uS, this figure becomes 65.6 uS. The nearest settable value to this figure is 64 uS, so this value should be used.

On the **TDR200 front panel**, set the value of **R2 = 0.5 * R1** and set the **PC** to display the input end waveforms. If necessary, adjust the **pulse width controls** on the **TDR200** unit until the waveforms are similar to those shown in figure 4.5(a) below.

Notice that the **waveform amplitude decreases** approximately **2 x SPT** after the start of the input pulse. This is caused by the **RSO pulse** being reflected with **negative polarity** due to the impedance mismatch at the end of the winding.

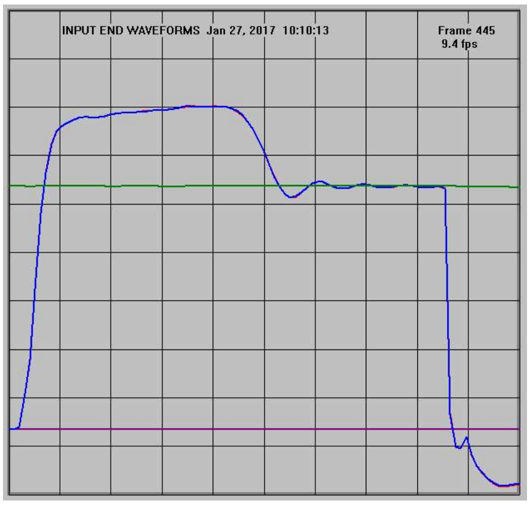


Figure 4.5(a) Typical input end end waveforms with R2 set to set to half R1 value.

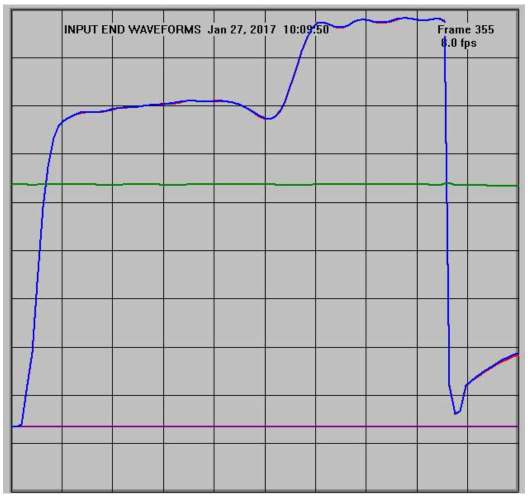


Figure 4.5(b) Typical input end waveforms with R2 set to 2X R1 value.

Now reset the value **of R2 = 2 * R1** and display the input end waveforms. These should be similar to those shown in figure 4.5(b). In this case, the waveform amplitude increases because the pulse is reflected with positive polarity from the end of the winding.

Note that:

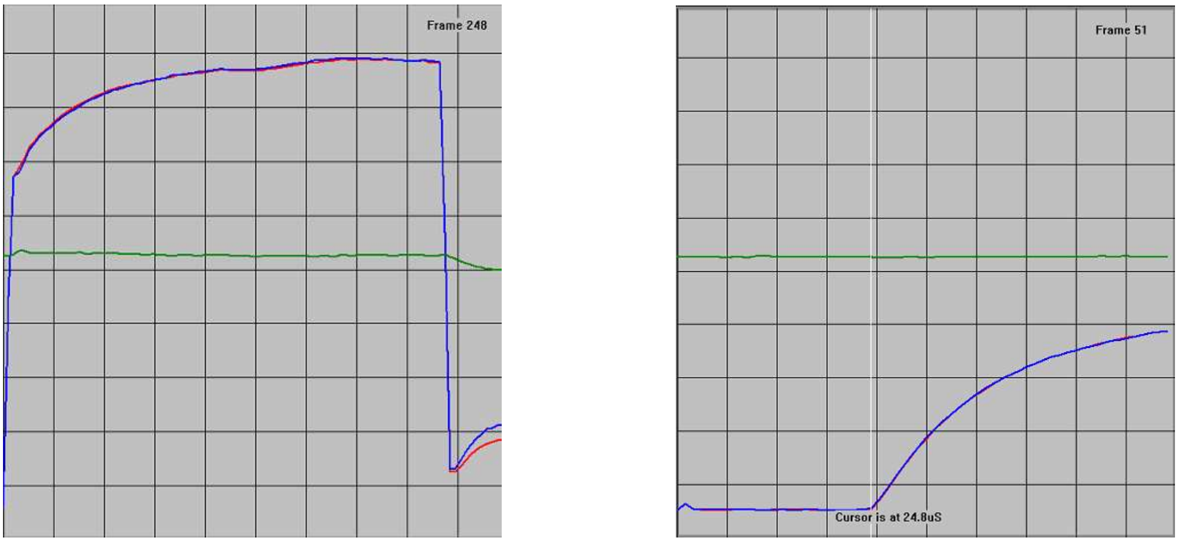
If **R2 is set to be > R1**, the reflected signal is **positive** and adds to the input waveform.

If **R2 is set to be < R1**, the reflected signal is **negative** and subtracts from the input waveform.

Now adjust **R2** so that there is no reflected signal after **2 x SPT**. This is the correct setting for **R2** and is the **characteristic wave impedance** of the rotor winding.

If necessary, adjust the setting of **R1** so that it is the same as **R2** to finish the impedance matching at the input ends. This minimises the possibility of multiple reflections from one end of the rotor to the other. It may now be necessary to adjust the display vertical sensitivity controls to optimise the trace size relative to that of the screen.

Finally, adjust the **TDR200 pulse width control** so that the waveforms resemble those shown in figure 4.6.



(a) Input end waveforms **(b) Output end waveforms**

Figure 4.6 Correct RSO waveforms for a fault-free rotor winding.

PART 2

Part 2 contains sections 5 to 8 which describes the operation of the **TDRPlot software** in detail as follows:

5. This describes the operation of the **TDRPlot software** which controls the operation of the **TDR200** system in **Digital mode** under the **control of a PC**. The next 3 sections (6 - 8) describe the operation of the 3 main **TDRPlot windows** in detail

6. The **TDRPlot** software **Control window.**

7. The **TDRPlot** software **Plot window.**

8, The **TDRPlot** software **Files window.** This section also gives information about the **format** of the **data files** and also their **location**, and includes instructions for exporting this data to a spreadsheet.

5. OVERVIEW OF THE TDRPLOT SOFTWARE

The next few sections describe the **TDRPlot software**, which controls the operation of the **TDR200** system in **Digital mode**.

5.1 HARDWARE AND SOFTWARE CONFIGURATION

The **Control PC** is connected to the **TDR200** unit using a standard USB printer lead and the control software (**TDRPlot.exe**) is used to display and capture the rotor waveforms.

The **TDRPlot** software can operate in either **Real-time** or **Playback** modes.

In **Real-time** mode, the software controls the **TDR200** unit to capture, display **live RSO waveforms** and saves them to both **text** and **bitmap** data files

In **Playback** mode, the software can be used to display and analyse a **previously-captured** data file.

All of the program and data files are contained within a single folder (the **"Default folde**r") on the **Control PC**. This **default folder name** is **C:\TDRPlot.** Most of the **data files** generated by the software are saved to a **Data Files subfolder** of the **Default folder**.

When the **TDR200** is operated in **digital mode** using a **Control PC** running the **TDRPlot** software, the **pulse repetition (scan) rate** is set by the **control software** instead of the **Frequency** control on the **TDR200** front panel (which is **inoperative** in **digital control mode**).

The **rotor input and output end waveforms** can still be displayed and observed by connecting an oscilloscope to the **TDR200 oscilloscope terminals**, as in analogue mode, but an oscilloscope is no longer necessary, as the primary method of displaying the waveforms is now the screen of the **Control PC.**

A pair of high-resolution 16 bit Analogue to Digital Converters (ADCs) in the **TDR200** digital interface are used to digitise the waveforms at the input and output ends of the rotor winding and to construct frames of data containing the waveforms at the input and output ends. In **digital mode**, the **waveform frames** are built up using a number of sequential measurement scans (RSO pulses), where the number of scans per measurement frame depends on the **scanning resolution** set by the user.

5.2 PROGRAM WINDOWS

The **TDRPlot** software generates 3 windows when it is run as follows:

A **Control Window** which allows the user to set/select the required **control parameters** and **file names** etc.

A **Plot Window** which displays the **measured waveforms**.

A **Message Window** which is primarily used for diagnostic purposes and error-checking etc.

5.3 DATA FILES

5.3.1 Input files

In Real-time mode, the **TDRPlot** software uses an **input data file** to initialise the **control parameters**. This file (**T200ini.txt)** contains the last used values for the control parameters. This file is always loaded by default when the program is run.

A similar **customini.txt** file, which holds set up data for a specific measurement configuration, can also be defined and loaded by the user to update the control parameters to a new measurement configuration.

In **Playback** mode, the **TDRPlot** software can be used to load and display waveforms and data files previously captured during **Real-time** mode operation.

5.3.2 Output files

The software generates a number of **output files** in a **Data Files** sub-folder:

When the **TDRPlot** program is terminated in **Real-time** mode using the **Exit button**, the **control window parameters** and the **last frame of data** are saved to 3 **default** data files and also to 3 **custom** data files.

The **default** file names are:

T200ini.txt which contains the set of **control window parameters** on exit.
Lastframe.txt which contains the set of **ADC readings for the last frame of data**.
Lastframe.bmp which contains a **bitmap image of the last plot window**.

The **custom** file names, which contain similar data are:

RotorID$-ini.txt
RotorID$.txt
RotorID$.bmp

where **RotorID**$ is the rotor ID (name) as specified in the top text box of the **Control window**.

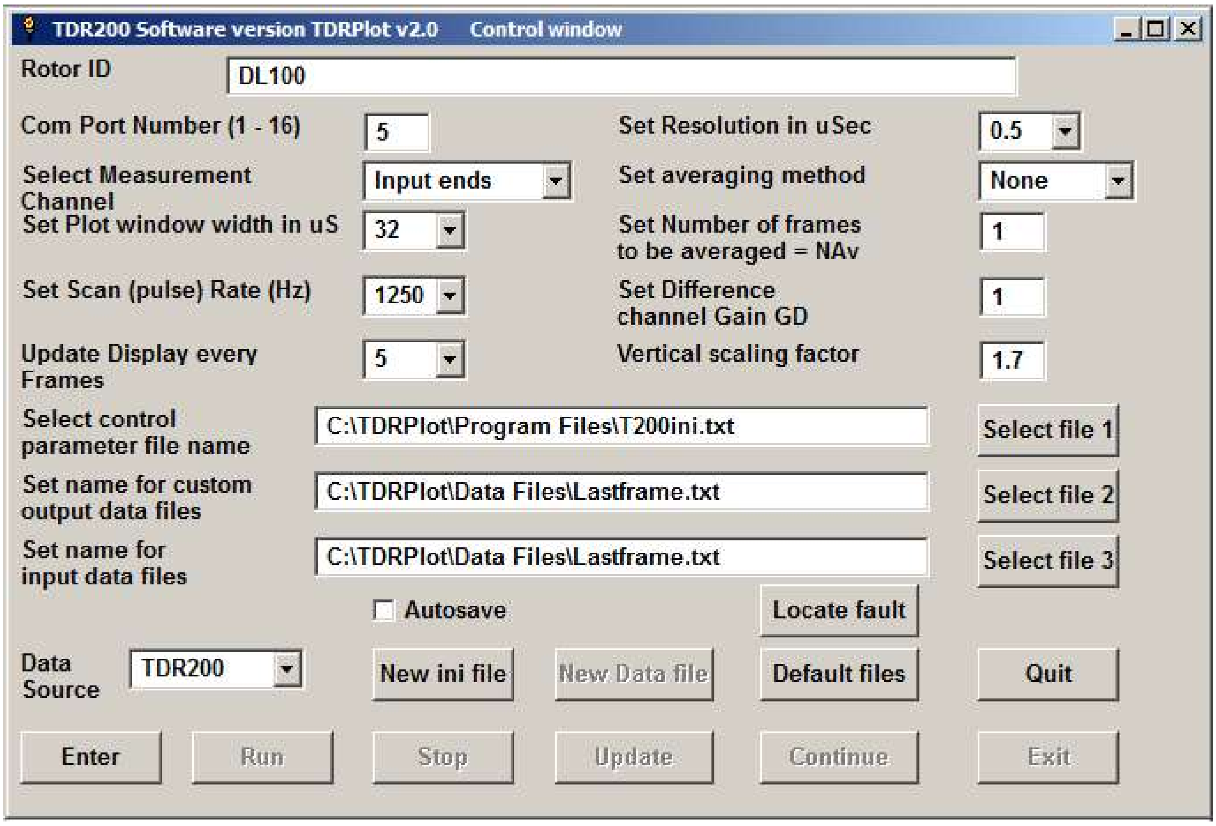
Note that the **T200ini.txt** file is saved to the **Program files** folder **C:\TDRPlot\Program files**, whereas all of the other files are saved to the **Data files** folder **C:\TDRPlot\Data files**.

In addition, data can be saved for any data frame by pausing data capture and using the **Save** button in the **Plot window**.

Detailed information about the data file formats with examples is given in section 8.

5.4. THE CONTROL WINDOW.

When the program is run, a **Control window** appears as shown in **Figure 5.4.1** below. This window contains the **control parameters** which must be set before the program is run. The program retains the last-used control parameters by default in the **T200ini.txt** file and also in an optional **custom ini** file if one has been defined by the used..



TDR200 Software version TDRPlot v2.0   Control window

Rotor ID: DL100

Com Port Number (1 - 16): 5

Set Resolution in uSec: 0.5

Select Measurement Channel: Input ends

Set averaging method: None

Set Plot window width in uS: 32

Set Number of frames to be averaged = NAv: 1

Set Scan (pulse) Rate (Hz): 1250

Set Difference channel Gain GD: 1

Update Display every Frames: 5

Vertical scaling factor: 1.7

Select control parameter file name: C:\TDRPlot\Program Files\T200ini.txt

Set name for custom output data files: C:\TDRPlot\Data Files\Lastframe.txt

Set name for input data files: C:\TDRPlot\Data Files\Lastframe.txt

☐ Autosave

Data Source: TDR200

Figure 5.4.1. Control window

Full details of the **Control window** parameters are given in section 6.

5.4.1 RUNNING THE SOFTWARE USING THE DEFAULT CONTROL PARAMETERS IN REAL-TIME MODE

Set the **Data Source box** to the **Real-time mode** of operation by selecting the **TDR200** (default) option.

Now run the program by clicking on the **Enter** and **Run** buttons in sequence. The software will run and live RSO data will be displayed in the **Plot window**.

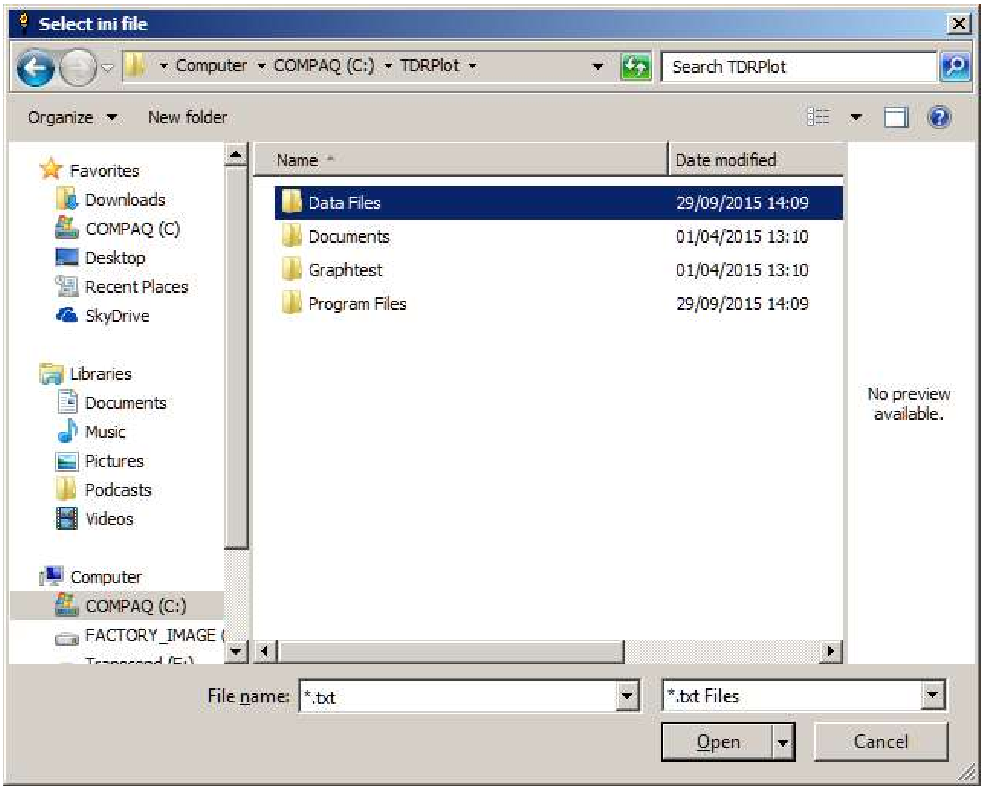
Next terminate the program using the **Stop** and **Exit** buttons in sequence. The **last frame of data** will automatically be saved to files with the names **Lastframe.txt,** which contains the set of **ADC** readings for the last frame of data and **Lastframe.bmp,** which contains a **bitmap image** of **the Plot window** for this data frame. A number of other files may also be generated, as described later.

5.4.2 LOADING A NEW SET OF CONTROL PARAMETERS

If the **control parameters** which are loaded on opening the program are not correct for the rotor to be tested, they can either be editted manually or changed by reading the correct data from a custom **control parameter file** (assuming one has been saved on a previous occasion).

A new **control parameter file** for a different rotor can be loaded as follows:

Use the **Select file 1** button to browse for the the required **control parameter file**. This file will be in the **Data files** folder.



Name	Date modified
Data Files	29/09/2015 14:09
Documents	01/04/2015 13:10
Graphtest	01/04/2015 13:10
Program Files	29/09/2015 14:09

File name: *.txt

*.txt Files

Figure 5.4.2 The Select file window

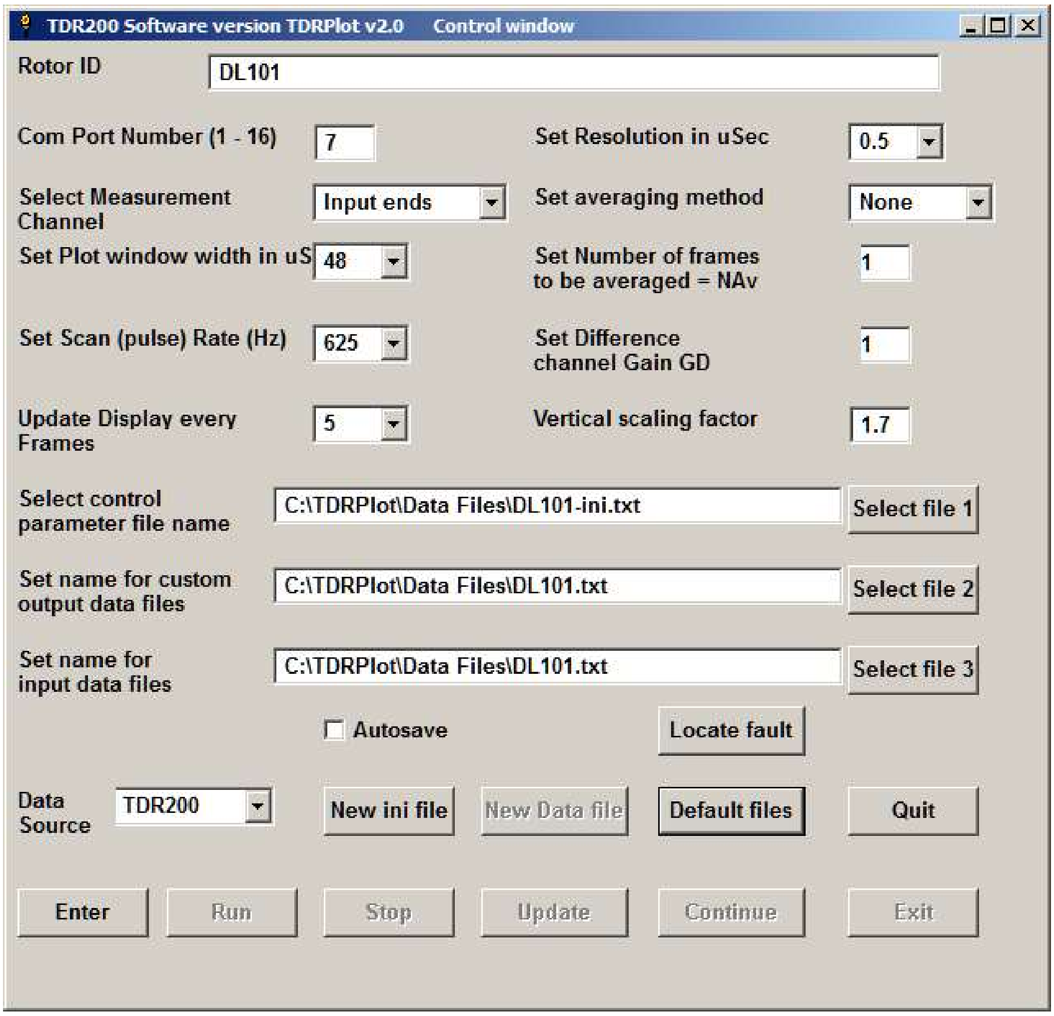
Open the **TDRPlot\Data files** folder and select the required **control parameter file**, which will have the form: **Name-ini.txt**.

Then click on the **New ini file** button. This will read the contents of the selected file to the **text boxes** in the **control window**.

If the output file names do not follow the naming rules, click on the **Default files** button to set the output data files to the default names for this new Rotor.

5.4.3 SAVING FILES TO NEW DEFAULT FILE NAMES

If the **Default files** button is clicked, the set of 3 data file names in the **Control window** are set to default names based on the **Rotor name** entered in the **Rotor ID** box at the top of the **Control window**, as shown in **Figure 5.4.3**



TDR200 Software version TDRPlot v2.0 Control window

Rotor ID: DL101

Com Port Number (1 - 16): 7

Set Resolution in uSec: 0.5

Select Measurement Channel: Input ends

Set averaging method: None

Set Plot window width in uS: 48

Set Number of frames to be averaged = NAv: 1

Set Scan (pulse) Rate (Hz): 625

Set Difference channel Gain GD: 1

Update Display every Frames: 5

Vertical scaling factor: 1.7

Select control parameter file name: C:\TDRPlot\Data Files\DL101-ini.txt

Set name for custom output data files: C:\TDRPlot\Data Files\DL101.txt

Set name for input data files: C:\TDRPlot\Data Files\DL101.txt

☐ Autosave

Data Source: TDR200

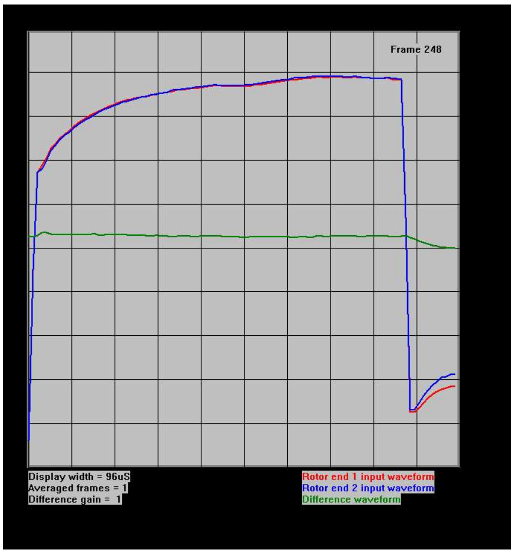
Figure 5.4.3 Setting new default file names

This can be a useful feature for setting unique file names for each rotor type or test.

Note that the **output data file** will be **over-written** on program exit in **Real-time** (**TDR200**) mode, so it may be necessary to use unique Rotor ID names for each test if relying on the data saved on program exit.

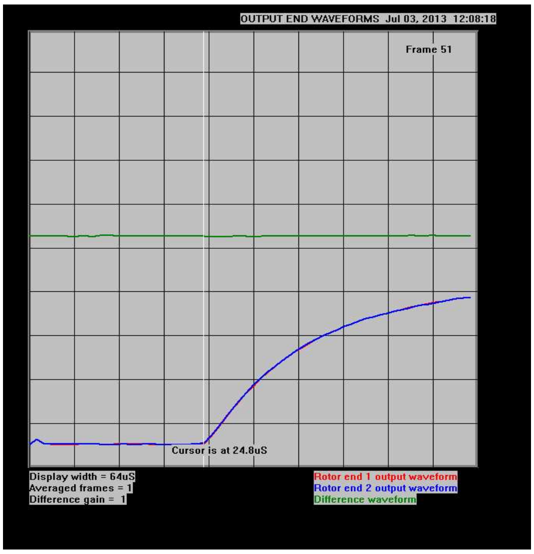
5.5 THE PLOT WINDOW

Once the **control parameters** have been modified or confirmed, the program is run by clicking the **ENTER** button, followed by the **RUN** button. This generates a **Plot window**, shown in simplified form for a **fault-free rotor winding** in figure 5.5.1 below.



Display width = 96uS
Averaged frames = 1
Difference gain = 1

Figure 5.5.1 Plot window showing input end waveforms for a fault-free rotor winding



Display width = 64uS
Averaged frames = 1
Difference gain = 1

Figure 5.5.2 Plot window showing output end waveforms for a fault-free rotor winding

The **Plot window** shows the rotor waveforms at either the **input, output** or **both ends** of the **rotor winding** depending on the option set in the **Measurement Channel selection box** in the **Control window**.

Figure 5.5.1 shows the waveforms at the **input ends** of the windings for a fault-free rotor. As well as the 2 input waveforms (shown in red and blue), the difference between these 2 waveforms is shown in green. It is also possible to display (white) time cursors as described later.

Similarly, figure 5.5.2 shows the **Plot window** in simplified form for the **output ends** of the rotor winding

The **width** of the **Plot window** (**Plot width**) is set in the **Control window**. However, the actual width of the **applied RSO pulse** is still set by the **TDR200 unit**.

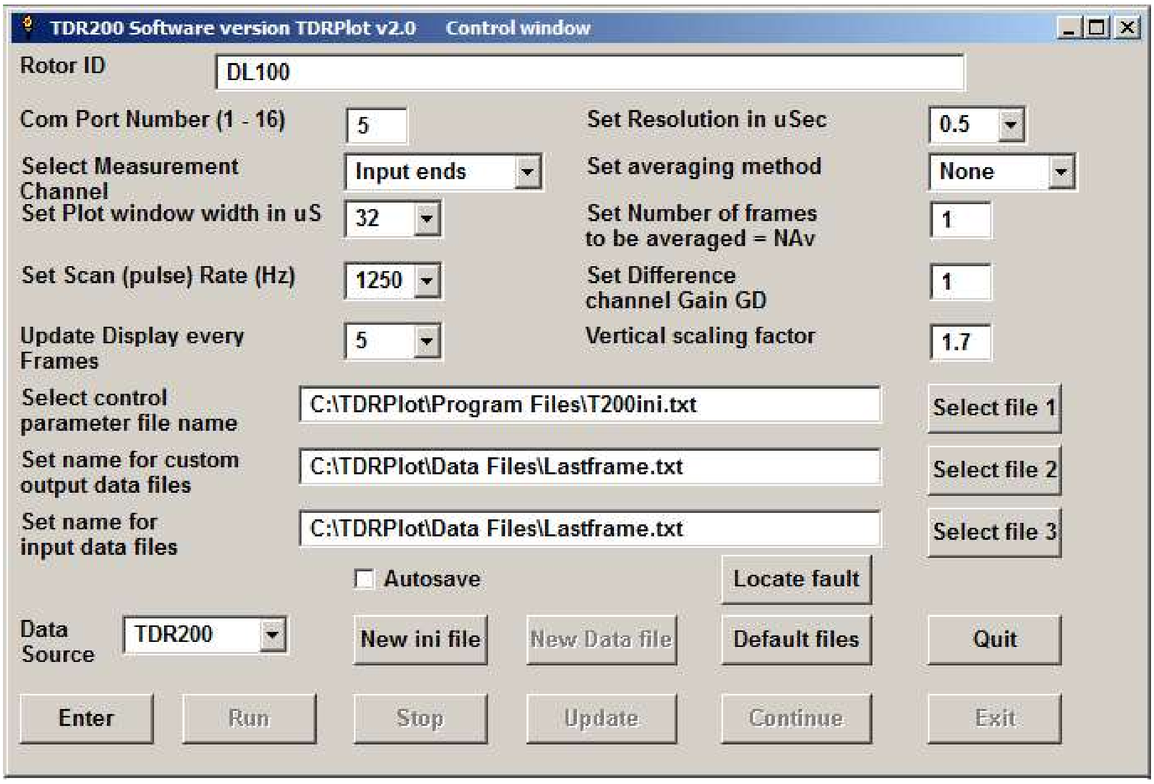
Full details of the **Plot window** parameters are given in section 7.

6. CONTROL WINDOW DETAILED INFORMATION

This section describes the functions of the **parameters** and **buttons** in the **Control Window** in more detail.

When the **TDRPlot program** is opened, the parameters in the **Control window** are loaded from the **default control parameter file T200in.txt** and the values appear in the text boxes. These parameters will have the values set when the program was last run.

A typical start-up window is shown below, where **DL100** is the nominated RotorID.



TDR200 Software version TDRPlot v2.0 Control window

Rotor ID: DL100

Com Port Number (1 - 16): 5

Select Measurement Channel: Input ends

Set Plot window width in uS: 32

Set Scan (pulse) Rate (Hz): 1250

Update Display every Frames: 5

Set Resolution in uSec: 0.5

Set averaging method: None

Set Number of frames to be averaged = NAv: 1

Set Difference channel Gain GD: 1

Vertical scaling factor: 1.7

Select control parameter file name: C:\TDRPlot\Program Files\T200ini.txt

Set name for custom output data files: C:\TDRPlot\Data Files\Lastframe.txt

Set name for input data files: C:\TDRPlot\Data Files\Lastframe.txt

☐ Autosave

Data Source: TDR200

Figure 6.1 The Control window

6.1 CONTROL WINDOW PARAMETERS

Details of the **Control window** set up parameters are as follows:

1. Rotor ID:

A user-entered Name (character string) which identifies the rotor being tested. (Max 64 characters). As this name is also used to define the names of the stored output data files, it helps to choose a fairly short or abbreviated Rotor ID name.

2. Com Port Number:

The number of the **com port** on the laptop PC connected to the **TDR200 reflectometer.** Details for obtaining or setting this number are given **in Appendix 1.8.**

3. Select measurement channel

To view the waveforms at the input ends of the rotor, select **Input ends**.
To view the waveforms at the output ends of the rotor, select **Output ends**.
To view the waveforms at both ends of the rotor, select **Both ends**.
Typical parameter values are given in (Purple) in some of the following paragraphs.

5. Set Plot window width

This parameter sets the width of the waveform plotting window in integer multiples of 16uS. A suitable value for the test delay line is 48uS.

Note that the actual applied RSO pulse width is set by the **front panel controls** of the **TDR200** unit.

6. Set Scan (pulse) Rate (Hz)

When the **TDR200** unit operates in **digital mode** under **PC contro**l, the **Frequency control** on the front panel of the **TDR200** unit is inoperative.

Instead, the repetition rate of the applied voltage pulse is set by the **Set Scan (pulse) Rate (Hz)** parameter in the **Control Window**. In general, this should be set to the highest rate possible (1250).

7. Update Display every N frames

The value of **N** selected determines how often the **Plot window** is updated. For example, if N = 5, the plot window is updated after every 5 frames of measured data. (5)

8. Set Resolution parameter

This parameter sets the effective sampling rate for the displayed waveforms in multiples of 0.1us.

(A suitable resolution value for the supplied delay line is 0.5uS).

9. Set averaging method

This allows data for consecutive frames to be averaged to reduce any noise in the displayed waveforms. The options are **None, Rolling** or **Exponential** with the following meanings:

None: No averaging
Rolling: Frames are averaged using a true rolling average algorithm
Exponential: Simple cumulative averaging using an exponential averaging algorithm.

10. Set Number of frames to be averaged NAv

This parameter (**NAv**) sets the number of frames to be averaged (5)

11. Set difference channel gain

This parameter (GD) allows the gain applied to the difference channel to be modified as required. The normal (default) value is 1.

12. Vertical scaling factor:

This parameter allows the vertical span (height) of the displayed waveforms to be adjusted. Valid values for this parameter are in the range between 0.5 and 2 (1.6).

13. Select control parameter file name:

This data file is generated as an option by the **TDRPlot** software and contains initialisation parameters for a **specific Rotor or test site**.

14. Set name for custom output data files:

This sets the **first part** of the **file name** for any **output files** generated by the use of the **Save button** in the **Plot window**.

15. Set name for input data files:

This sets the name of the file to be used as input data when the system is used in **Playback** mode (by selecting the **File** option in the **Data source** box).

16. Autosave check box: (This feature is currently unavailable)

If this box is ticked, A bitmap image of the plot window is saved after every 1000 frames. The default mode at start-up is not ticked.

17. Data Source select box:

Selects **Real-time** (TDR200) or **Playback** (File) mode of operation. **Default mode** is **TDR200** (Real-time).

6.2 CUSTOM DATA FILE NAMES

The **custom data file names** are specified in the **3 file name** boxes in the **Control window.**

Standard file names derived from the **Rotor ID name** can be generated automatically by clicking on the **Default files** button.

Although it is possible to set different **output file** names by using the **Select file 2** button (for example to identify different tests of the same rotor) it is preferable to edit the rotor file name instead (eg RotorID-1, RotorID-2) to identify the results for different test conditions. The **file name box** details are as follows:
.

1. Set name for control input parameters

This box contains the **file name** for the control input parameters to be used.

2. Set name for custom output data files (on-line mode)

This box contains the **file name** for the output data files.

3. Set name for custom input data files (off-line mode)

This box contains the file name for the input data file to be read in off-line mode.

6.3 CONTROL BUTTON DETAILS

The functions of the various **buttons** in the **Control window** are as follows:

Enter: Used to confirm the data defined in the **Control Window** before running the program.

Quit: Used to quit the program before the **Run** button is clicked. The **Quit** button is inoperative once the **Run** button has been selected. Use the **Exit** button to quit the program after it has been run.

Run: Used to run the program after the control data has been confirmed by use of the **Enter** button.

Both the **Enter** and **Run** buttons become inoperative after the **Run** button is clicked for the first time. Use the **Update** and **Continue** buttons instead to modify any of the control parameters after stopping or pausing the scanning (see below).

Stop: Used to Stop the program to allow the control data to be changed.

Update: Used to confirm the modified control data.

Continue: Used to restart the program after updating the control data. Note that when the **Stop Scan/Continue** buttons are used, the frame count is reset to 1 when the **Continue** button is clicked.

To stop the scanning while retaining the frame count, use the **Pause/Resume** buttons in the **Plot window** instead of the **Stop Scan/Continue** buttons in the **Control window** (see section 5).

Exit: Used to exit the program after the **Stop button** has been clicked.

When the **Exit button** is clicked, a number of files are generated as detailed in section 8.

New ini file: This is used to load a new control parameter data file and its operation is described in detail in **section 5.3**.

New Data file: Used to select a **new data file** to be viewed in **persistence mode** without erasing the previous data (**Playback** mode only).

Default files: Used to set the file names to default names based on the Rotor ID.

Select File buttons: Used to select **control parameter**, **output** or **input** data files for previously saved specific measurement configuration or data. See **section 6.2** for more information.

Locate button: This runs a macro-program which calculates the fault location from a set of RSO measurements as described in section **15.4**.

6.4 LOADING A NEW SET OF CONTROL PARAMETERS

If the **control parameters** which are loaded on opening the program are not correct for the rotor to be tested, they can either be edited manually or changed by reading the correct data from a custom **control parameter file** (assuming one has been saved on a previous occasion).

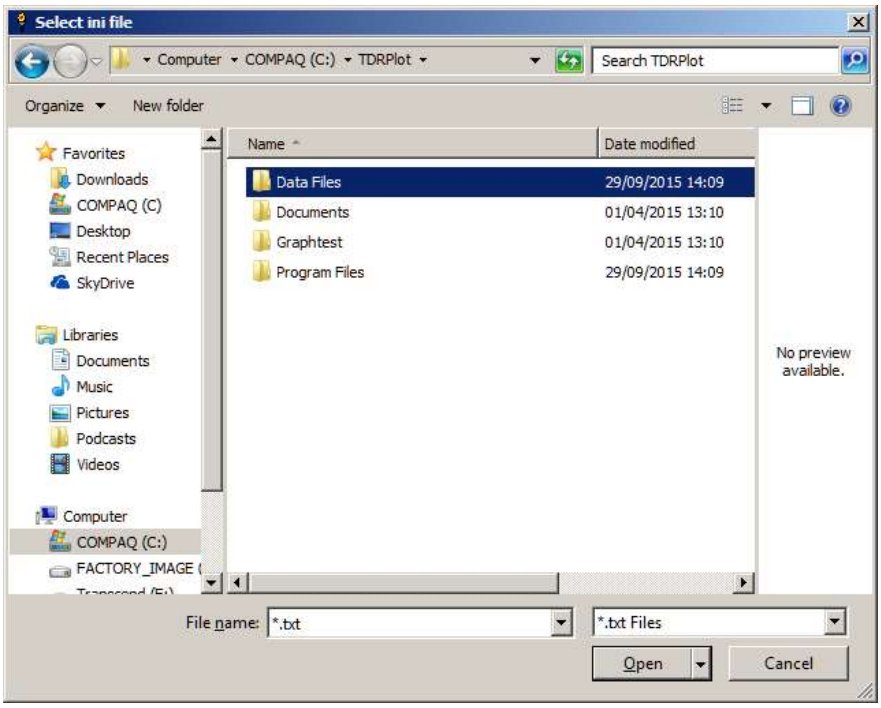
A new **control parameter file** for a different rotor can be loaded as follows:

Use the **Select file 1** button to browse for the the required **control parameter file**. This file will be in the **Data files** folder.

Open the **TDRPlot\Data files** folder and select the required **control parameter file**, which will have the form: **Name-ini.txt**.

Then click on the **New ini file** button. This will read the contents of the selected file to the **text boxes** in the **control window**.

If the output file names do not follow the file-naming rules, click on the **Default files** button to set the output data files to the default names for this new Rotor.



Name	Date modified
Data Files	29/09/2015 14:09
Documents	01/04/2015 13:10
Graphtest	01/04/2015 13:10
Program Files	29/09/2015 14:09

File name: *.txt

*.txt Files

Figure 6.4.1 Selecting a new control parameter (ini) file

6.5 LIMITATIONS ON THE VALUES OF THE CONTROL PARAMETERS

The **maximum horizontal resolution achievable is 0.1 uS**, but the amount of internal memory in the **TDR200** imposes a limit on the **combination** of **resolution** and **plot window width** for the captured waveforms. As the **plot window width** (time) is increased, the maximum resolution achievable decreases.

For example, for displaying data at either the **input** or **output ends** of the rotor winding at the maximum resolution of 0.1uS, the longest possible data capture time corresponds to 48uS. When the **Control window** is set to display data at **both ends** of the winding simultaneously, the maximum window width is 24uS.

It is therefore necessary to **reduce the measurement resolution** accordingly when **longer plot window times** are required. Alternatively set the software to display the waveforms at either the input or output ends only..

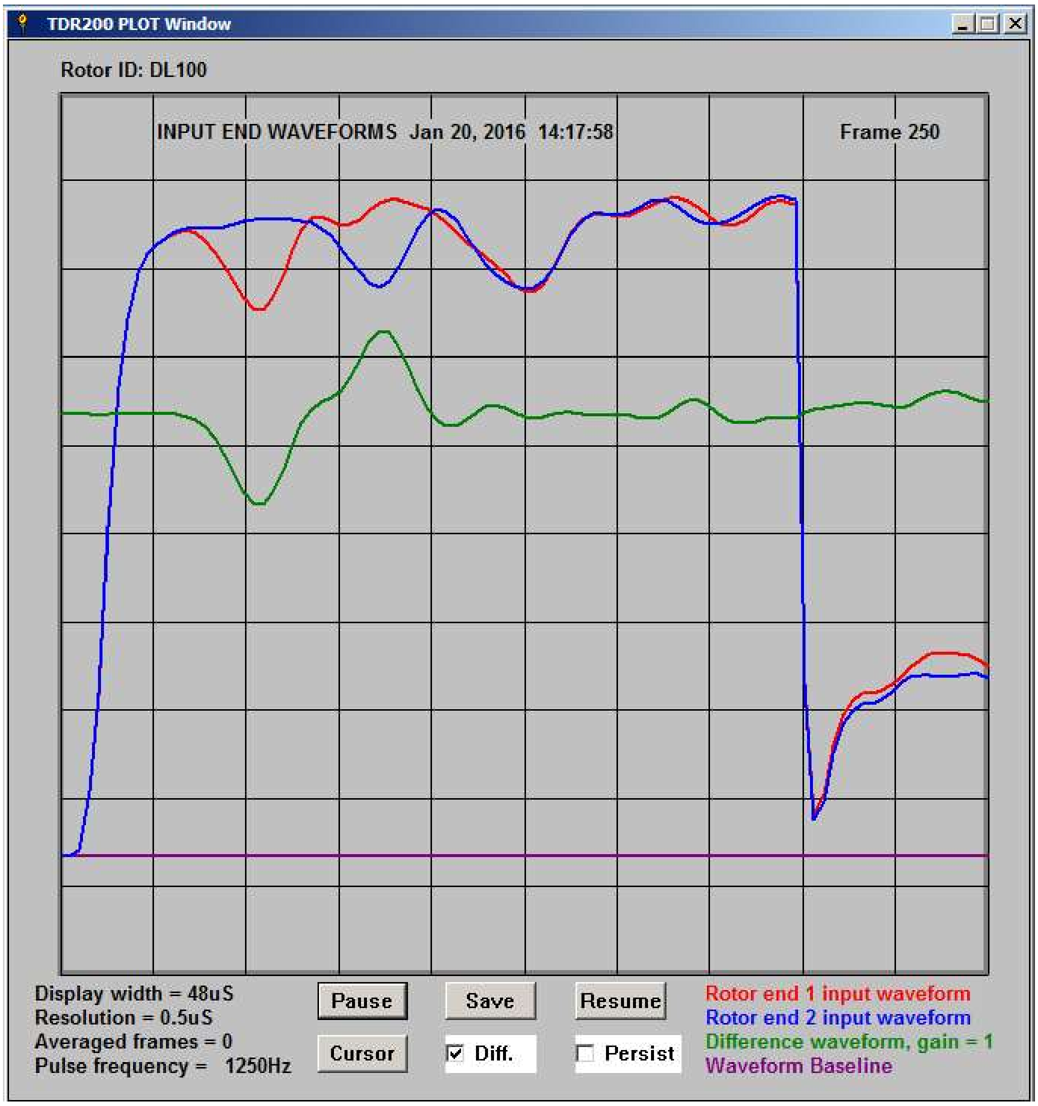
Note that as both the **plot window width** and **measurement resolution** are increased, the **time to capture a frame of data also increases**.

There is also a limit on the **pulse scan rate** when long pulse widths are set on the **TDR200** unit, as high pulse repetition rates can result in potentially damaging power dissipation in the internal electronic circuitry. Consequently, when the **TDR200 pulse width switch** is set to the highest pulse width setting, the maximum **pulse scan rate** is restricted to **250 Hz**. If attempts are made to set a higher pulse rate, this is detected by the software and a value of **250Hz** is set automatically in the **Control Window**.

If attempts are made to exceed the permitted combinations of pulse width, measurement resolution and/or pulse rate, a number of **warning windows** are displayed.

7. THE PLOT WINDOW

This section describes the detailed operation of the **Plot Window**



Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

☑ Diff.
☐ Persist

Figure 7.1 The Plot window for the test delay line with simulated shorted coil

7.1 DISPLAY DETAILS

The **Plot window** displays the **rotor waveforms** at either the **input** or **output** or **both ends** of the **rotor winding** depending on the option set in the **Measurement Channel selection box** in the **Control window**. Figure 7.1 shows the waveforms at the **input ends** of the demonstration **delay line** containing a simulated inter-coil fault. The waveform for end 1 is shown in **Red,** the waveform for end 2 is shown in **Blue**, and the difference between these 2 waveforms is shown in **Green.** The waveform baseline is shown in **Purple**.

The **width** of the **Plot window** (**Plot width**) is set in the **Control window** and is shown at the bottom left hand corner of the window. However, the actual width of the **applied pulse** is still set by the pair of front panel controls on the **TDR200 Reflectometer**. Other parameters displayed in this part of the window are the **horizontal resolution**, **number of frames averaged** and the **pulse frequency**.

7.2 CONTROL BUTTONS

The functions of the **Control buttons** in the **Plot window** are as follows:

Pause button: Stops the scanning and allows use of the remaining control buttons and the mouse pointer for cursor generation (see below).

Save button:

When this button is clicked, the **current waveform image frame** is saved as a **bitmap file** in the **Data Files** subfolder, with a filename of the form **customout-frame number.bmp.** Any number of frames can be saved to individual file names using the **Save button**. A similar **text file** of data is also generated.

Note that when the **Save** button is pressed in **Real-time mode**, both **bit-map** and **data text files** are generated.

However, in **Playback mode**, only **a bit-map image file** is saved, but with a modified file name to indicate that it has been generated from **file input data**.

Resume button:

Clicking on this button erases the current **Plot window** and resumes scanning and plotting the next frame number. (Note that the use of the **Pause/Resume** buttons to stop the scanning retains the **frame count,** whereas the use of the **StopScan/Continue** buttons in the **Control Window** resets the frame count to zero.)

Cursor button:

The use of the **Cursor** button is optional, as clicking on the **Pause** or **Stop** buttons automatically enables the **mouse cursor** function.

When the cursor function has been enabled, a **vertical white cursor line** appears at the **horizontal location** of each point on the screen at which the mouse is clicked and the corresponding **time from the start of the pulse** is displayed in the **waveform plot area**.

A new cursor line is displayed for each mouse click, but the time displayed corresponds to the last mouse click only.

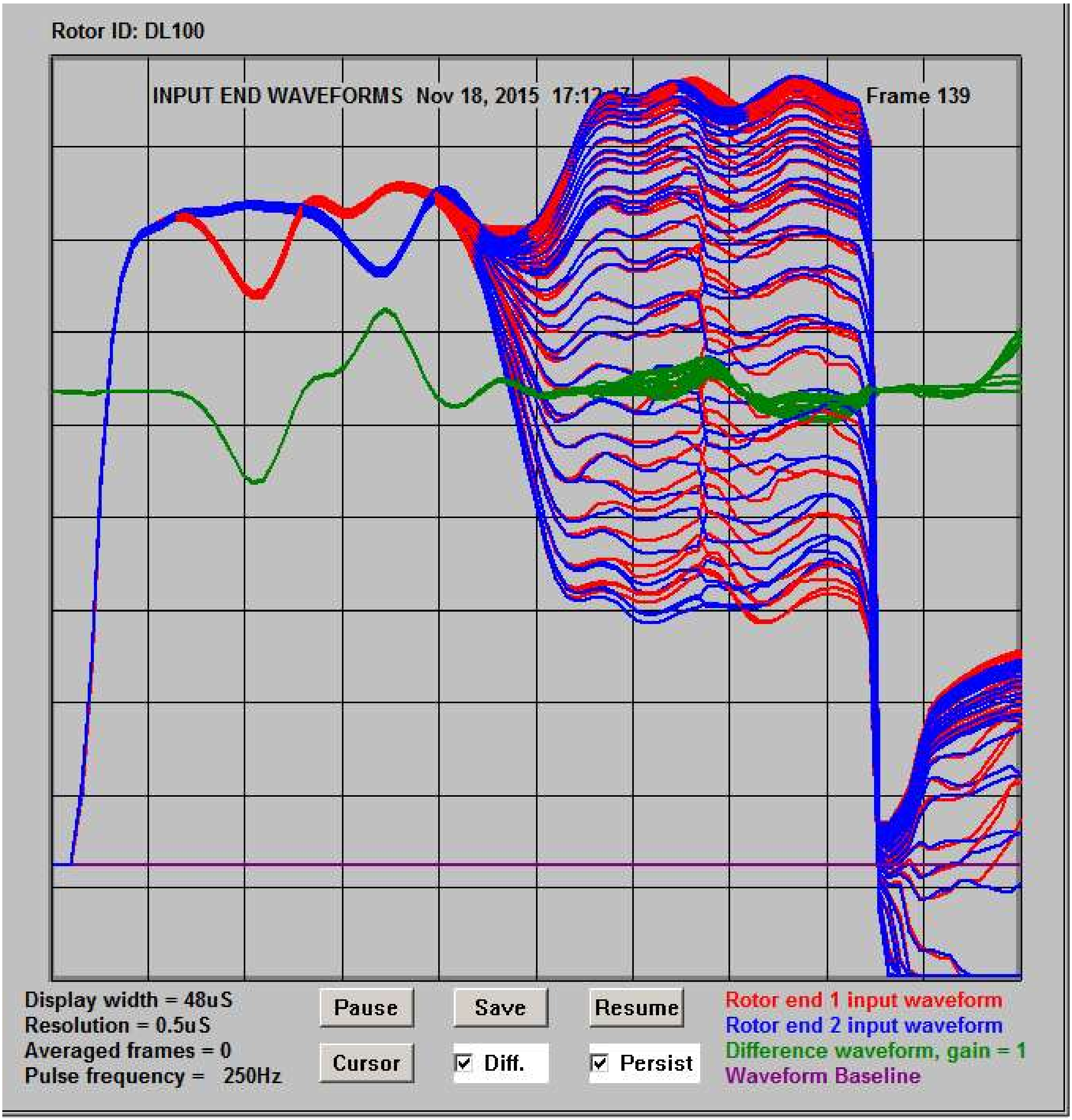
When the **input end waveforms only** are displayed, the cursor text also shows the **percentage difference** between the **end 1 (red)** and **end 2 (blue)** waveforms.

Diff Check box:

If checked, this displays a trace which plots the difference between the 2 input or output end waveforms. This box is ticked by default at program initialisation.

Persist check box:

If checked, the display area is not cleared between successive data frames. This allows successive data frames to be compared. The following plot shows the effect of adjusting the terminating impedance R2 when **persistence mode** is enabled.



Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

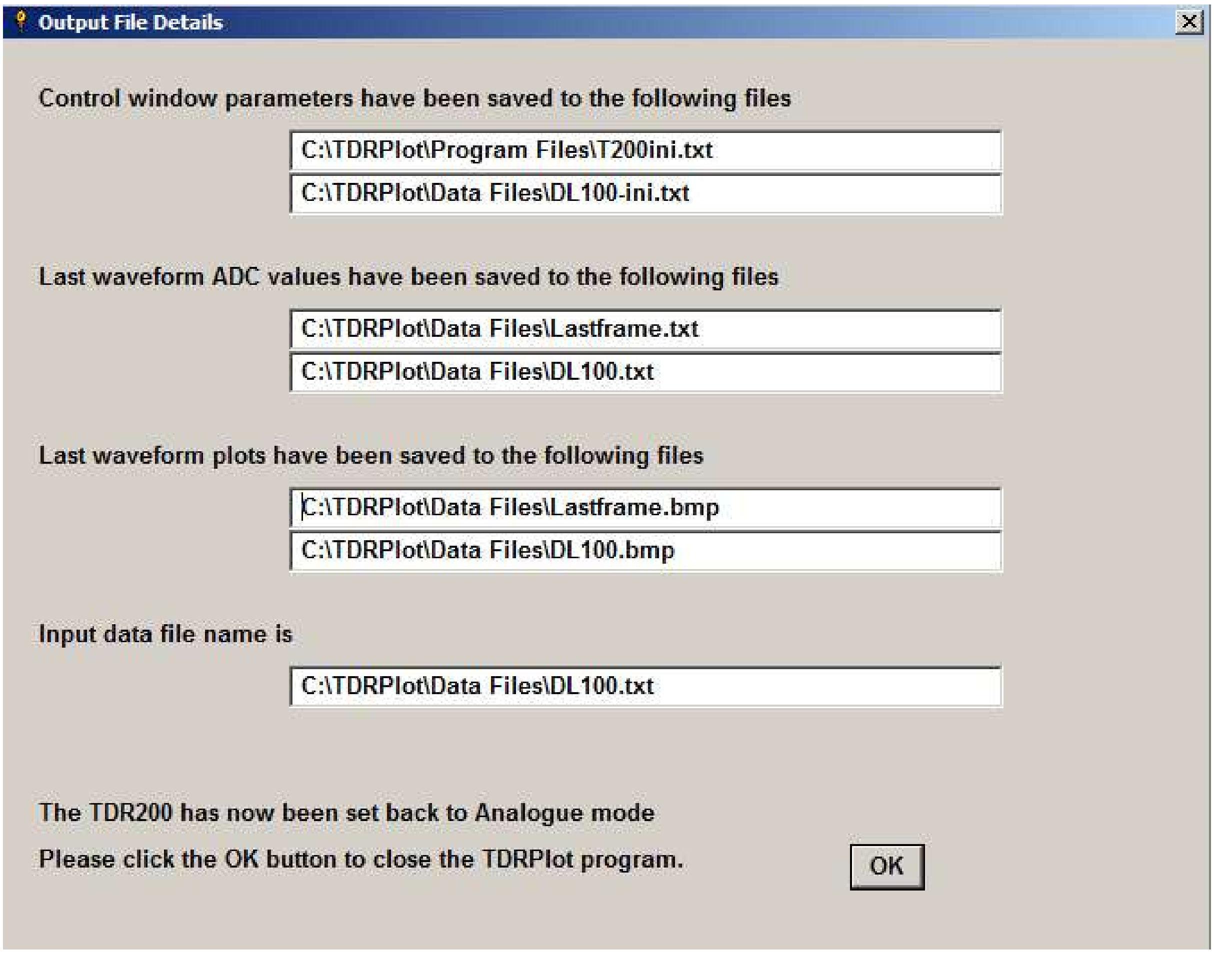
Figure 7.3.1. Use of persistence mode

Persistence mode can be useful for measuring the **double-pass transit time** of the rotor winding. It can be used in both **on-line** and **off-line** modes and can therefore be used to compare historical data files.

8. THE OUTPUT FILE DETAILS WINDOW

8.1 FILES GENERATED FOLLOWING USE OF EXIT BUTTON

When the **Exit button** is clicked, a number of files are generated and are summarised in the **Output File Details** window.



Control window parameters have been saved to the following files

C:\TDRPlot\Program Files\T200ini.txt

C:\TDRPlot\Data Files\DL100-ini.txt

Last waveform ADC values have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.txt

C:\TDRPlot\Data Files\DL100.txt

Last waveform plots have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.bmp

C:\TDRPlot\Data Files\DL100.bmp

Input data file name is

C:\TDRPlot\Data Files\DL100.txt

The TDR200 has now been set back to Analogue mode

Please click the OK button to close the TDRPlot program.

Figure 8.1 The Output File Details window.

The **Output File Details window** lists the full names of the files which contain the **last frame of data** before the **Exit button** was clicked.

By default, this data is always saved to the filenames **Lastdata.txt** (as a set of integer ADC readings) and **Lastframe.bmp** (as an image bitmap file).

In addition, the same data is saved to **Custom file names** if these have been defined in the **Control window**.

The **output data files** are saved by default to the **Data Files subfolder** when the **OK button** is clicked to exit the program. These files should be copied to individual folders elsewhere on the PC immediately after data capture for security and for possible use in other software.

8.2. SOFTWARE AND DATA FILE LOCATIONS

8.2.1 PC FOLDER STRUCTURE

All of the software and data files are installed to a **(Default) Master folder C:\TDRPlot.** This folder also contains **subfolders** for **Program files**, **Data files** and **Documentation**.

8.2.2 MASTER FOLDER

The **Master folder** contains the following sub-folders:

Program Files
Data Files
Documentation

8.2.3 PROGRAM FILES SUB-FOLDER

The Program Files folder contains the following files:

TDRPlot.exe : The main program file and associated DLLs
T200ini.txt : A data file containing the last-used values for the control parameters.

8.2.4 DATA FILES SUB-FOLDER

The **Data Files** sub-folder contains the following files:

Lastframe.bmp File containing a bit-map image of the last plot image window before the program was terminated.

Lastframe.txt File containing the ADC readings for the 3 waveforms in the last frame of data before the program was terminated.

Custom.bmp which is similar to **TDRPlot.bmp** but has a file name (in this case, **Custom**) which can be chosen by the user.

Customini.txt which contains the set of measurement configuration data defined by the user and can be used instead of the standard **T200ini.txt** initialisation file.

In both cases, the Custom text will be the full file name as specified in the Configuration window.

8.2.5 DOCUMENTATION SUB-FOLDER

The **documentation folder** contains a set of **User manuals** and other related documentation.

8.3 FILE NAME DETAILS

When the **TDRPlot** program is terminated in **On-line** mode using the **Exit button**, the **control window parameters** and the **last frame of data** are saved to 3 **default** data files and also to 3 **custom** data files.

The **default** file names are:

T200ini.txt which contains the set of **control window parameters** on exit.
Lastframe.txt which contains the set of **ADC readings for the last frame of data**.
Lastframe.bmp which contains a **bitmap image of the last plot window**.

The **custom** file names, which contain similar data are:

RotorID$-ini.txt
RotorID$.txt
RotorID$.bmp

where **RotorID**$ is the rotor ID (name) as specified in the top text box of the Control window.

Note that the **T200ini.txt** file is saved to the **Program files** folder **C:\TDRPlot\Program files,** whereas all of the other files are saved to the **Data files** folder **C:\TDRPlot\Data files**. Detailed information about data file formats with examples is given in **section 8.7**.

8.4 SETTING THE CUSTOM FILE NAMES

The **custom data file names** are specified in the **3 file name** boxes in the **Control window**.

Standard file names derived from the **Rotor ID name** can be generated autoatically by clicking on the **Default files** button.

8.5 SETTING NON-DEFAULT FILE NAMES

Although it is possible to set different output file names by using the Select file 2 button (for example to identify different tests of the same rotor) it is preferable to edit the rotor file name instead (eg RotorID-1, RotorID-2) to identify the results for different tests conditions.

8.6 FILES GENERATED FOLLOWING USE OF SAVE BUTTON

When data capture is paused and the **Save** button is clicked in the **Plot window**, the **current waveform image frame** is saved as bitmap and text files in the **Data Files** subfolder, with filenames of the form **customout-frame number.bmp/txt.** Any number of frames can be saved to individual file names using the **Save button.**

Note that in **off-line mode**, only **a bit-map image file** is saved, but with a modified file name to indicate that it has been generated from **file input data**.

8.7. FILE FORMATS

This section explains the format and gives examples of the various data files used by the **TDR200** software.

8.7.1 CONTROL PARAMETER FILE FORMAT

These ASCII files (eg **T200ini.txt)** contain the set of parameters in the **Control window**. A typical example follows:

DL100	The Rotor ID
4	PC comport number
Input ends	Data type
48	Plot window width (uS)
0.5	Data resolution (uS)
500	Scan-rate (pps)
1	Number of frames to average
1	Difference Channel gain
C:\TDRPlot\Data Files\DL100-ini.txt	Control Parameter file name
None	Averaging method
C:\TDRPlot\Data Files\DL100.txt	Output data file name
5	Frame plot skip parameter
1.7	Vertical scaling parameter
C:\TDRPlot\Data Files\DL100.txt	Input data file name

New control data is saved to this file each time the TDRPlot software is closed (exited).

8.7.2 SAVED RSO FRAME DATA FILE FORMATS

This ASCII data file is generated each time the program is exited or the **SAVE** button in the **PLOT** window is used. The file contains a header section containing the data in the relevant **Control parameter** file, together with a data section containing sets of ADC readings for the waveforms at each end of the rotor winding and also the difference between these ADC values. The data corresponds to one RSO image frame.

Each line of data contains a set of 4 integer values for each data frame. Each set of frame data is terminated in a **Carriage Return** character. The individual data fields in each frame are separated by a single **SPACE** character.

The data for each frame consists of the following items with typical values shown below:

FRAME NUMBER	**END1 ADC VALUE**	**END2 ADC VALUE**	**END1 - END2 ADC ADC VALUES**
1	5135	4751	384

A sample data file is shown on the following sheets.. Note that the frame number, date and time are also included before the end (**Header End**) of the header section.

Both of these text files can be viewed using the **Windows Notepad** program.

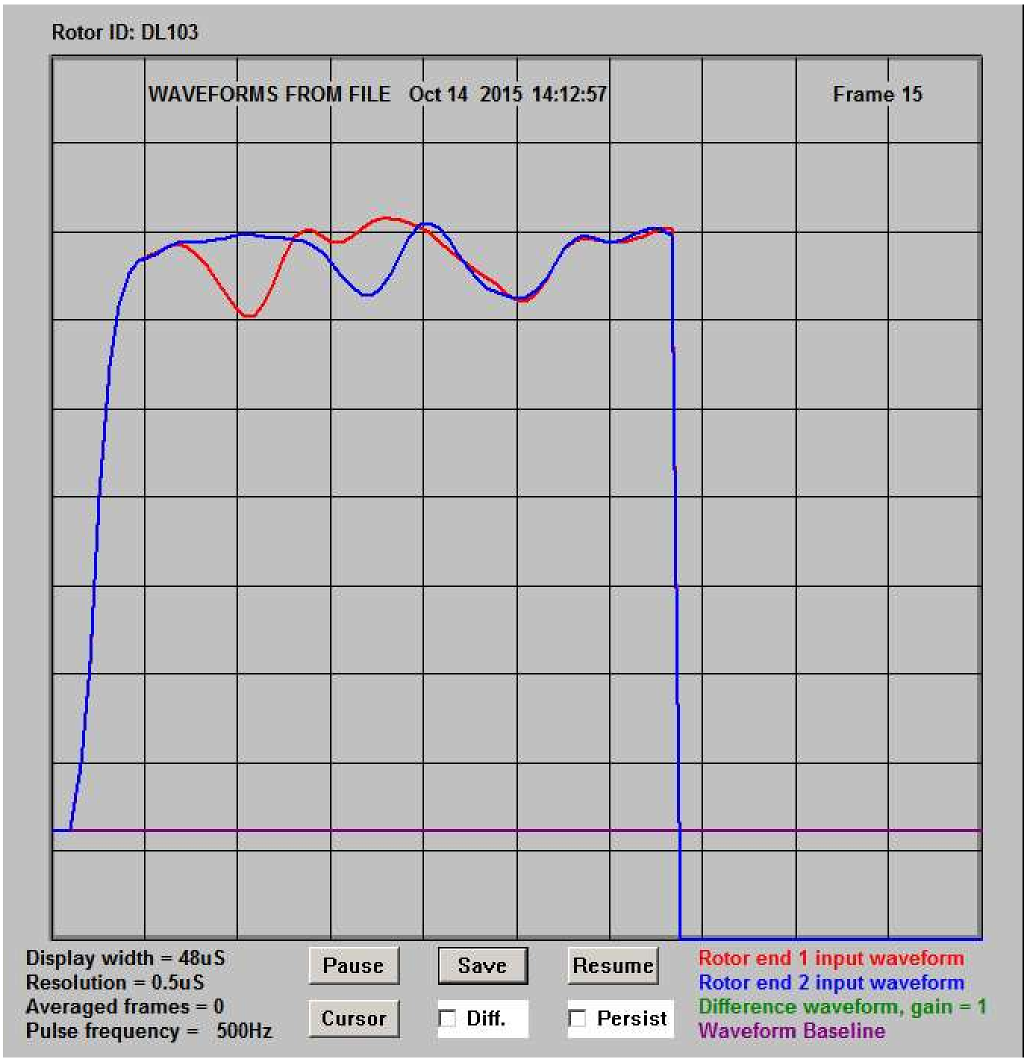
Example of RSO data file

```
DL100
4
Input ends
48
0.5
500
1
1
C:\TDRPlot\Program Files\T200ini.txt
None
C:\TDRPlot\Data Files\Lastframe.txt
5
1.7
C:\TDRPlot\Data Files\Lastframe.txt
15
Nov 16, 2015
17:45:23
Header End
1 4758 4763 -5
2 4776 4798 -22
3 7520 7521 -1
4 11754 11823 -69
5 18993 18986 7
6 24644 24638 6
7 27182 27186 -4
8 28645 28642 3
9 29119 29106 13
10 29301 29277 24
11 29495 29472 23
12 29706 29701 5
13 29800 29866 -66
14 29701 29925 -224
15 29389 29907 -518
16 28925 29921 -996
17 28341 29985 -1644
18 27692 30097 -2405
19 27102 30183 -3081
20 26741 30205 -3464
21 26794 30169 -3375
22 27331 30117 -2786
23 28256 30092 -1836
24 29277 30075 -798
25 30079 30043 36
26 30437 29938 499
27 30381 29738 643
28 30108 29419 689
29 29890 28990 900
30 29897 28503 1394
31 30132 28023 2109
32 30469 27681 2788
33 30797 27611 3186
34 30911 27923 2988
35 30898 28550 2348
36 30826 29357 1469
37 30711 30123 588
38 30526 30638 -112
39 30311 30766 -455
```

```
40 29969 30555 -586
41 29587 30045 -458
42 29244 29412 -168
43 28972 28831 141
44 28767 28403 364
45 28545 28135 410
46 28265 27983 282
47 27966 27901 65
48 27774 27898 -124
49 27835 28033 -198
50 28229 28391 -162
51 28900 28963 -63
52 29666 29655 11
53 30317 30307 10
54 30710 30749 -39
55 30839 30906 -67
56 30777 30843 -66
57 30663 30708 -45
58 30607 30650 -43
59 30642 30749 -107
60 30770 30971 -201
61 30939 31185 -246
62 31111 31270 -159
63 31235 31173 62
64 31274 30934 340
65 31168 30596 572
66 30950 30378 572
67 30671 30283 388
68 30427 30325 102
69 30325 30476 -151
70 30405 30697 -292
71 30583 30884 -301
72 30884 31103 -219
73 31138 31263 -125
74 31260 31317 -57
75 31216 31280 -64
76 31052 31162 -110
77 30832 31005 -173
78 30646 30845 -199
79 30347 30497 -150
80 7327 7142 185
81 5220 5152 68
82 5679 5586 93
83 6244 6118 126
84 8491 8333 158
85 9145 8971 174
86 9533 9353 180
87 9848 9657 191
88 10101 9900 201
89 10304 10088 216
90 10473 10227 246
91 10625 10348 277
92 10757 10448 309
93 10881 10533 348
94 10991 10612 379
95 11076 10670 406
96 11126 10709 417
End of ADC data
```

8.7.3 PLOT WINDOW IMAGE FILE

This file is a screen-shot of the Plot window in bit-map (.bmp) format. A typical example is shown below.



Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 500Hz

Figure 8.7.1 Typical Plot window image file

The .bmp files can be viewed using a suitable image display program such as **Irfanview**.

8.8. USING THE REFLECTOMETER IN PLAYBACK MODE

In **PLAYBACK** mode, the **TDRPlot** software can be used to display and analyse data from a **previously-captured** data file. This is done by setting the **Data sources** box to **File** and selecting the required file using the **Select 3** button in the **Control window**.

The data files contain a **header section** containing the control parameters and a **data section** containing the 16 bit ADC values measured for each waveform as described in detail in section 8.7.2

.

8.8.1 TO LOAD AND VIEW A CAPTURED DATA FILE

Set the **Data source** box to **File**

Select the required **input data file** using the **Select file 3** button.

Click on the **Enter** and then on the **Run** buttons. This will read and update the **Control parameter** data from the **file header section** and display the saved **RSO waveforms** in the **Plot** window.

8.8.2 TO VIEW DATA FROM ANOTHER DATA FILE:

Select a **new input data file** using the **Select file 3** button.

Click on the **New Data File** button. This will read and update the Control parameter data from the file header section and display the saved **RSO waveforms** in the **Plot** window.

8.8.3 TO VIEW DATA FROM ANOTHER FILE WITHOUT ERASING EXISTING WAVEFORM:

Note that this only makes sense if the 2 data files were captured using the same control parameters. Moreover the displayed text will be that for the first file loaded only.

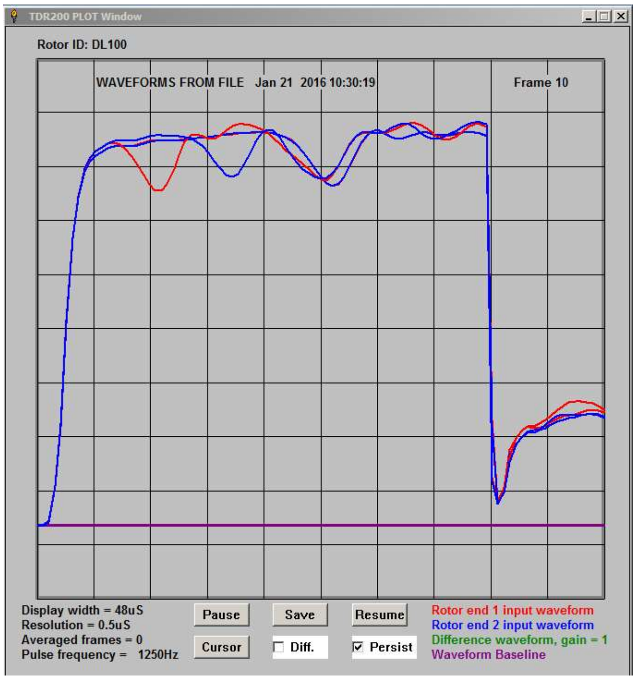
Tick **Persistence mode** box

Select the new input data file using the **Select 3** button.

Click on **New Data file** button**.**

This will select a **new data file** to be viewed alongside the previous data.

An example of viewing 2 data files simultaneously is shown in figure 8.8.1.



Rotor ID: DL100

WAVEFORMS FROM FILE Jan 21 2016 10:30:19

Frame 10

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

☐ Diff.
☑ Persist

Figure 8.8.1 Viewing 2 data files simulaneously in persistence mode

8.8.4 TO VIEW ONLY THE MOST RECENT FILE

Click the **Persist box** to disable **persistence mode.**

Click the **Continue** button.

8.8.5 TO EXIT THE PROGRAM OR REVERT TO ON-LINE MODE

Click on the **Exit** button. In **Playback mod**e, the **output window** is not shown as no output data files are saved or modified on program exit.

It is not possible to switch back to **on-line mode** directly from file mode. Instead, the program must be restarted following use of the **Exit** button.

8.9. IMPORTING THE RSO OUTPUT DATA TEXT FILE INTO A SPREADSHEET

Basic information describing how to import data from a **TDRPlot output text file** into MS **Excel** is given below.

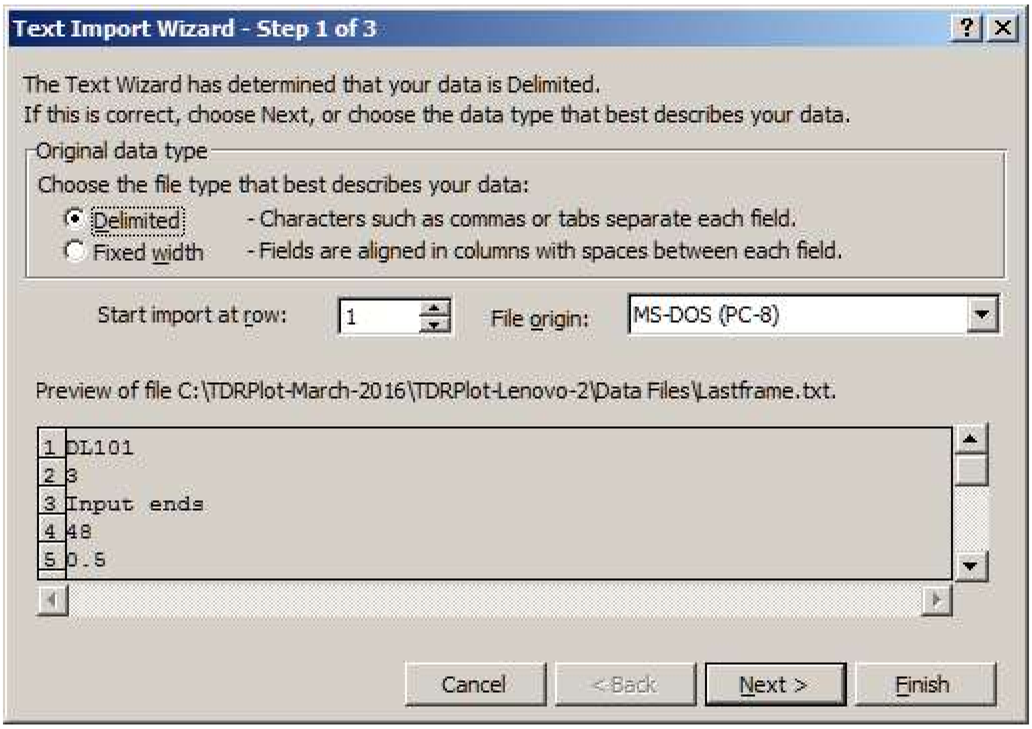
Open Excel

File > Open

Browse for eg **Lastframe.txt** file

> Open file

> Text import wizard window 1 opens



The Text Wizard has determined that your data is Delimited.
If this is correct, choose Next, or choose the data type that best describes your data.

Choose the file type that best describes your data:

● Delimited - Characters such as commas or tabs separate each field.
○ Fixed width - Fields are aligned in columns with spaces between each field.

Start import at row: 1

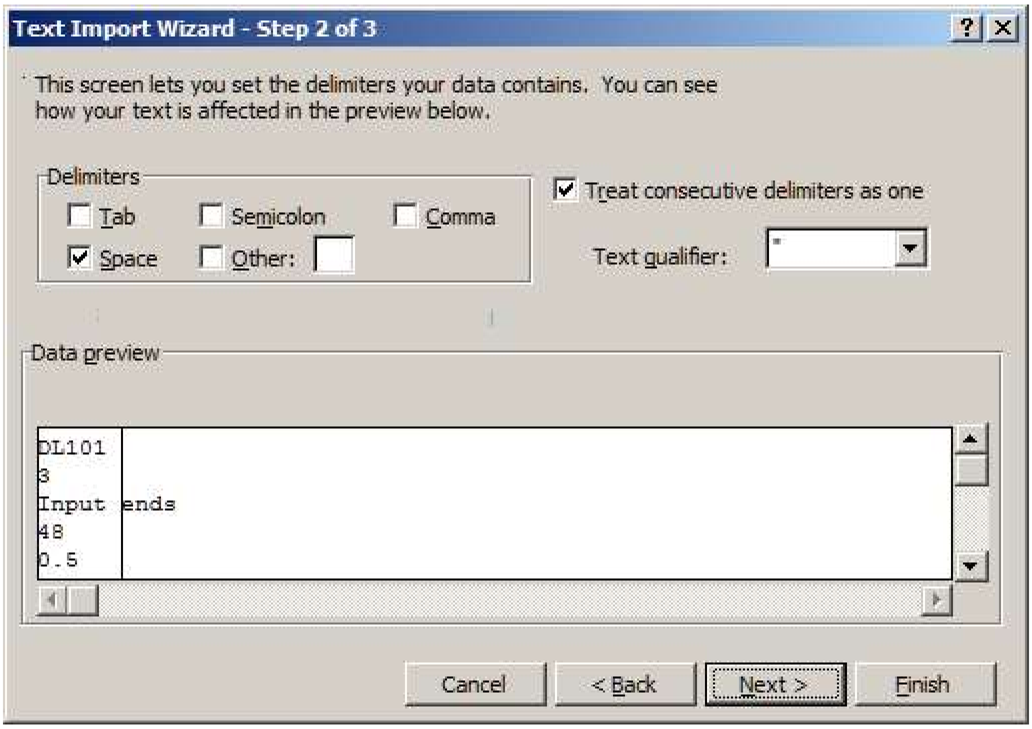
File origin: MS-DOS (PC-8)

Preview of file C:\TDRPlot-March-2016\TDRPlot-Lenovo-2\Data Files\Lastframe.txt.

```
1 DL101
2 3
3 Input ends
4 48
5 0.5
```

Click **Next**

> Text import wizard window 2 opens


Text Import Wizard - Step 2 of 3

This screen lets you set the delimiters your data contains. You can see how your text is affected in the preview below.

Delimiters

☐ Tab ☐ Semicolon ☐ Comma

☑ Space ☐ Other:

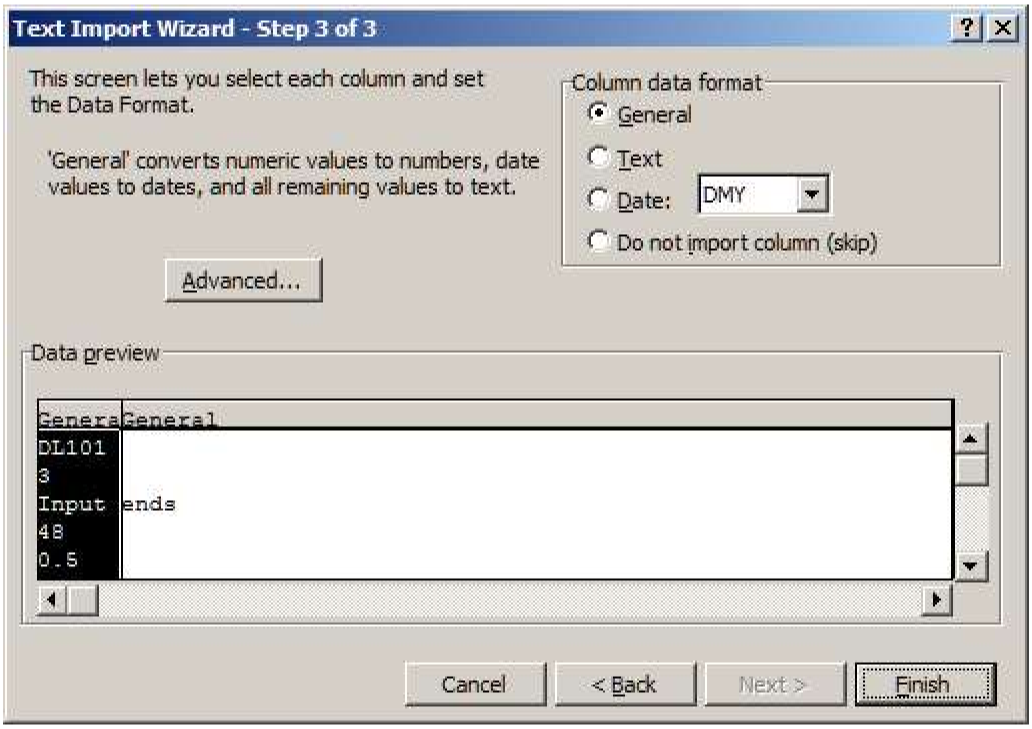
☑ Treat consecutive delimiters as one

Text qualifier: "

Data preview

```
DL101
3
Input ends
48
0.5
```

Select **Space** delimiter and click Next


Text Import Wizard - Step 3 of 3

This screen lets you select each column and set the Data Format.

'General' converts numeric values to numbers, date values to dates, and all remaining values to text.

Column data format

● General

○ Text

○ Date: DMY

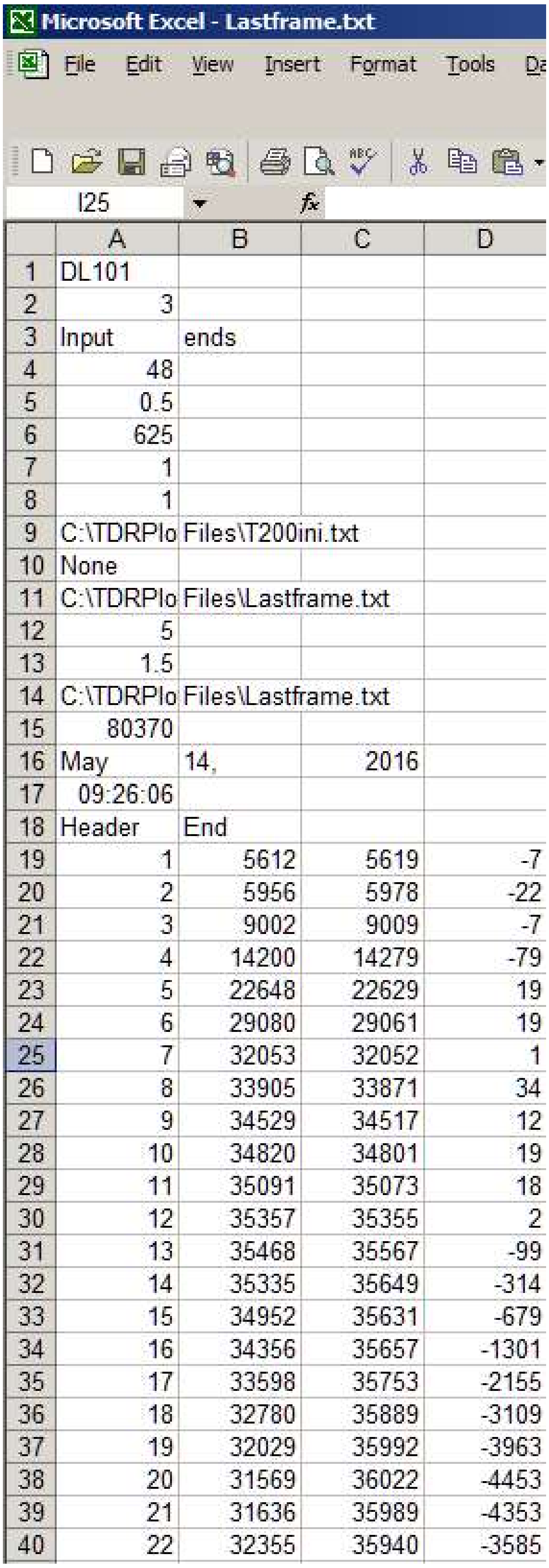
○ Do not import column (skip)

Data preview

```
GeneraGeneral
DL101
3
Input ends
48
0.5
```

Select **General** option for column data format then click **Finish**.

The data is imported to the spreadsheet. A typical example is shown below, where the first 18 lines contain header data and the remaining lines of data can be used to plot graphs etc.



	A	B	C	D
1	DL101			
2	3			
3	Input	ends		
4	48			
5	0.5			
6	625			
7	1			
8	1			
9	C:\TDRPlo	Files\T200ini.txt		
10	None			
11	C:\TDRPlo	Files\Lastframe.txt		
12	5			
13	1.5			
14	C:\TDRPlo	Files\Lastframe.txt		
15	80370			
16	May	14,	2016	
17	09:26:06			
18	Header	End		
19	1	5612	5619	-7
20	2	5956	5978	-22
21	3	9002	9009	-7
22	4	14200	14279	-79
23	5	22648	22629	19
24	6	29080	29061	19
25	7	32053	32052	1
26	8	33905	33871	34
27	9	34529	34517	12
28	10	34820	34801	19
29	11	35091	35073	18
30	12	35357	35355	2
31	13	35468	35567	-99
32	14	35335	35649	-314
33	15	34952	35631	-679
34	16	34356	35657	-1301
35	17	33598	35753	-2155
36	18	32780	35889	-3109
37	19	32029	35992	-3963
38	20	31569	36022	-4453
39	21	31636	35989	-4353
40	22	32355	35940	-3585

A simple **Excel graph plot of this RSO data** is shown next.

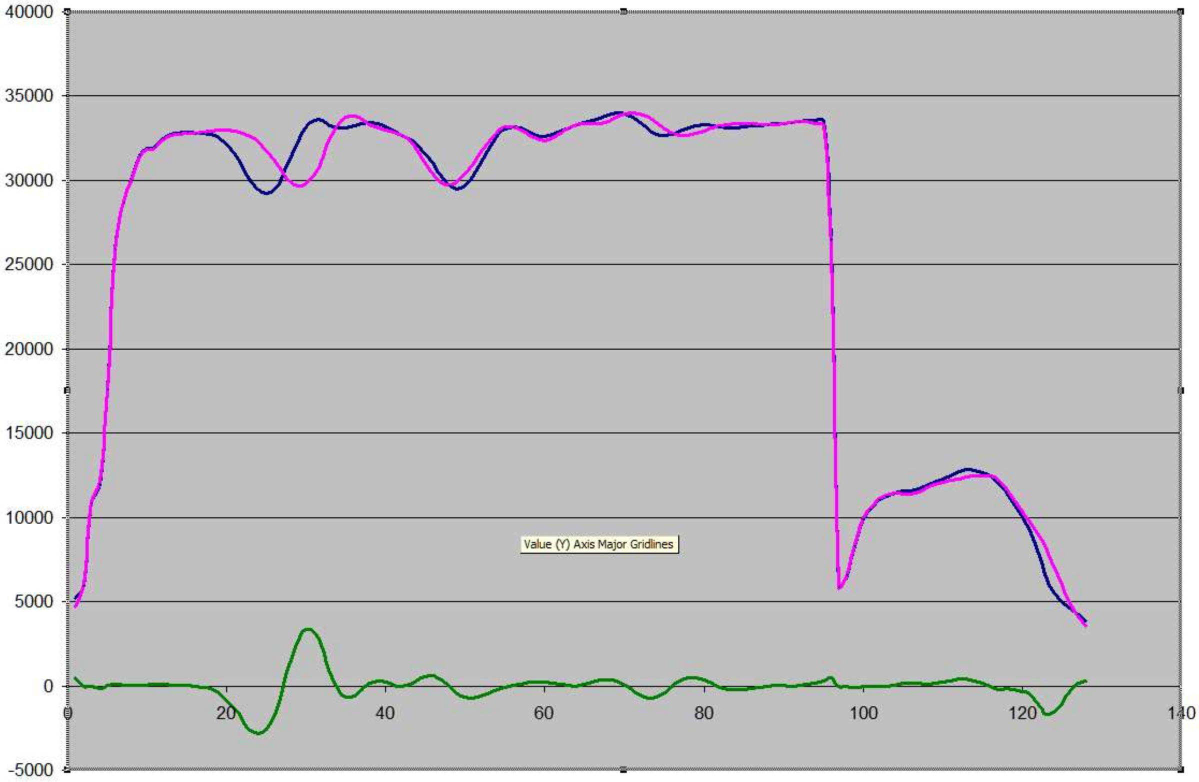


Figure 8.9.1 Excel plot of RSO waveform

PART 3

Part 3 contains sections 9 to 14 which contain practical information about using the **TDR200** to carry out RSO tests on real rotors under various testing conditions at rest and at speed.

The contents of each section are summarised below

9. This summarises the contents of the subsequent sections (10 to 14), which describe **practical aspects** of the different **RSO test scenarios** for testing **real rotors**.

10. This section describes the basic method for setting up the equipment to carry out an **RSO test** on a **stationary rotor** for operation in both **analogue** and **digital** modes

11. This section describes the test details when operating in **Digital mode.** It includes sample test results for a 660 MW rotor and **recommendations for recording the RSO tests** in a **standardised format**.

12. This section similarly describes the test details when operating in **Analogue mode.** It includes specific advice about using **digital oscilloscopes**.

13. Special arrangements are described for **testing a rotor at speed**. This includes information about preparing **insulated brushes** and methods for minimising brush contact problems.

14. This gives information relating to testing **laminated rotors**.

PRACTICAL ASPECTS OF RSO TESTING .9

This and following sections give **practical information** about the how the **RSO test** can be carried out under a range of operational scenarios and also how the **test results sould be .recorded**

9.1 SAFETY WARNING

The use of RSO test equipment on a rotor installed in an operational generator must be carried out with the explicit permission and under the supervision of the local plant operator. All local safety rules and procedures must be complied with.

In particular, the equipment must only be connected to the generator rotor after the field supply has been disconnected and completely isolated from the rotor winding, in accordance with local safety regulations. Failure to comply with this instruction will damage the test equipment and may endanger both the plant and the operator.

9.2 MEASUREMENT OPTIONS

There are several situations in which the RSO test can be used:

1) Stationary rotor installed in generator.

2) Rotor at speed in generator.

3) Rotor removed from generator.

4) Rotor under repair

9.3 TEST SEQUENCE

The basic steps to be carried out in all of the above options are as follows:

9.3.1 Carry out basic safety checks. (**Details in section 9.1** above.)

9.3.2 Isolate and prepare the rotor for testing. (**Details in section 10.2**)

9.3.3 Check the rotor winding for any obvious problems such as an earth faults or high winding resistance using a basic low-voltage multimeter. (**Details in section 10.3**)

9.3.4 Connect and set up the RSO test equipment. (**Details in section 10.4**)

9.3.5 Run the **TDRPlot** software and carry out the RSO test. (**Details in section 11.**)

9.3.6 Record the test results. (**Details in section 11.11**)

10. METHOD FOR TESTING A ROTOR AT REST WHILE INSTALLED IN THE GENERATOR

10.1 OVERVIEW

The most straightforward case is when the rotor is at rest in the generator and the test method for this will be described in detail. The other test modes are based on this technique with suitable modifications.

10.2 PREPARING THE ROTOR FOR TESTING

Before attempting to connect the Reflectometer to the rotor winding, the rotor winding must be completely isolated from the field supply, as described in the safety warning in section 9.1.

If the rotor has slip-rings, it may be necessary to remove all of the brushes to ensure complete isolation of the rotor winding. For rotors without slip-rings, the links to the exciter/rectifier diode wheel must be removed to achieve full isolation.

Low resistance connections must be made between the **Reflectometer**, **each end of the rotor winding and also to the rotor shaft.** Consequently, it will usually be necessary to clean both the rotor shaft and the slip rings adequately before making these connections.

10.3 CONNECTING THE REFLECTOMETER TO THE ROTOR WINDING

10.3.1 ROTOR WINDING CONNECTION MODULE AND TEST LEADS

The connections between the **Reflectometer** and the **Generator rotor winding** are made using the **Connection module** supplied with the equipment. This consists of a **3-core 5m** mains lead, terminated in **4mm insulated banana plugs** at the **Reflectometer end** and a **Connection box** terminated in **4mm insulated terminals** at the **rotor end.** The **Connection module** and **test leads** are shown in figure **figure 10.1** below**.**

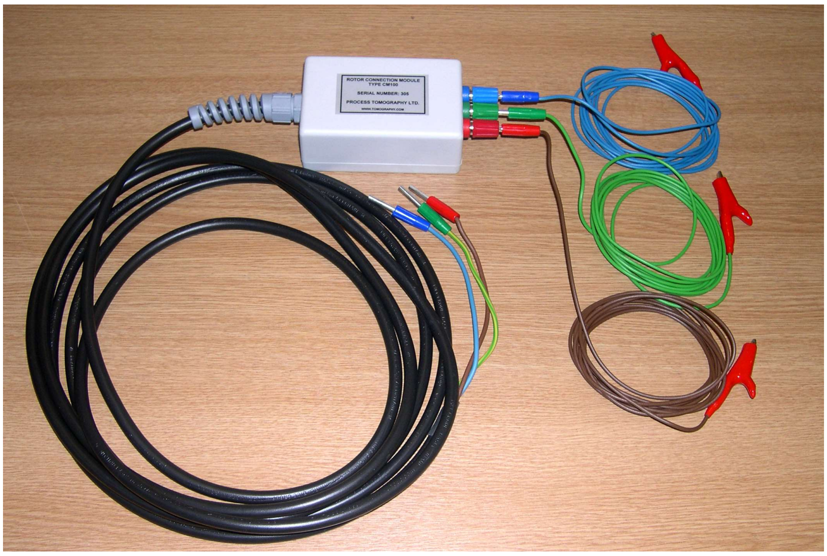


Figure 10.1 Rotor test leads and connection module

Note: The connection module provides simple 1:1 connectivity between the colour-coded banana plugs and terminals at the **reflectometer end** and the **output terminals** on the module. Three x 3m insulated single core leads terminated in insulated crocodile clips are used connect this module to the rotor winding.

This arrangement has been used to allow connections to be made to the rotor windings of large generators, where there may be significant distances between the slip rings and the rotor shaft earthing point. It also allows damaged connecting leads to be repaired or replaced easily on-site, or for customers to use their own connecting leads if preferred.

If the rotor has slip rings, the connections to the rotor slip rings and earthed shaft can be made by removing the circular steel keepers from the supplied contact magnets (figure 10.2) and placing the magnets onto the cleaned slip rings and the rotor shaft. The crocodile clips can then be attached to the screws on the magnets.

10.3.2 MAKING CONNECTIONS TO THE ROTOR WINDING

1. Isolate and make safe the generator stator winding according to the local site safety regulations.

2. Isolate the rotor winding from the excitation system as follows:

Either isolate the field brushgear from the field supply (both sets of brushes), or remove all of the brushes from each brushgear cage, ensuring that none of the brushes touch the slip rings or cages. For a brushless generator, isolate the generator field winding from the rotating rectifier diode wheel unit (both leads).

3. Connect the banana plugs of the individual 3m leads to the output terminals of the **Connection Module**. Match the plug and terminal colours (red to red etc.).

At this stage, do not connect the other end of the 5m test lead to the Reflectometer terminals.

Figure 10.2 Contact magnets and keepers.

4. Clean an area of rotor shaft adjacent to the slip rings with emery cloth, followed by a degreasing solvent and wipe off with a clean rag. Remove the magnetic keeper and attach one of the terminal magnets supplied (see figure 10.3) to the shaft at this point.

5. Attach the crocodile clip of the **green** conductor of the **3m Green test lead** to the screw stud on this magnet.

6. Attach the crocodile clips of the **brown** and **blue 3m test leads** to each end of the rotor field winding as follows:

If it has been possible to isolate the brushgear cages from the field supply, then simply connect these leads to each brushgear cage assembly (clip the crocodile clip on to one of the brush braids).

If the brushes have been removed, clean a small area on each slip ring with degreasing solvent and attach the two remaining magnets to the slip rings. Attach the **brown** and **blue** leads to the terminal studs on these magnets using the crocodile clips.

For the case of a brushless generator, clip the **brown** and **blue** leads directly to the up-shaft field winding leads after the isolating links have been removed.

Figure 10.3 shows the TDR200 Reflectometer connected using magnets to the slip rings and earth shaft of a rotor which has been removed from its stator.

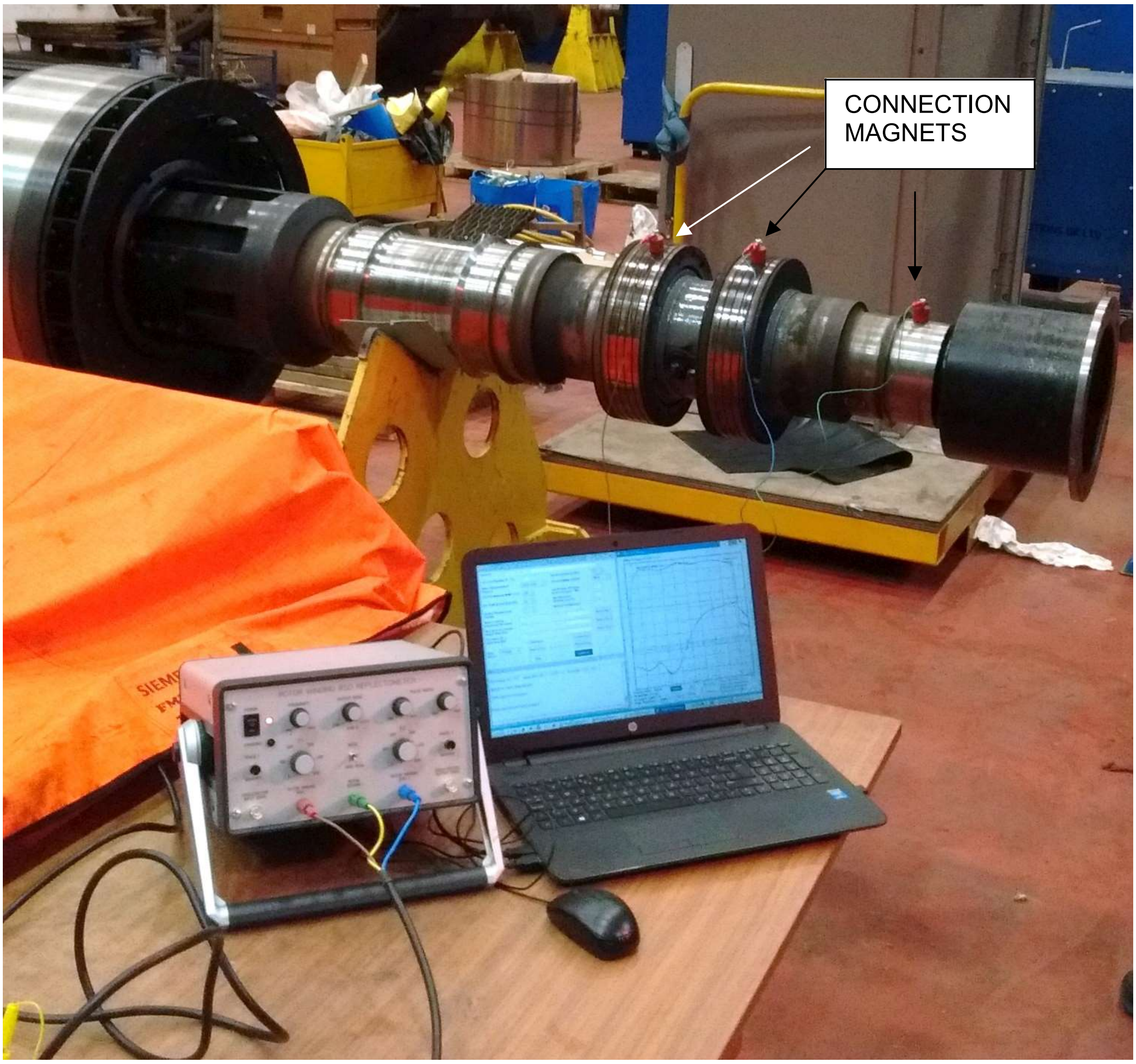


Figure 10.3 TDR200 Reflectometer connected to a rotor for a static RSO test

10. Using a low-voltage electrical test meter, measure the **rotor winding resistance** between the **red** and **blue banana plugs** at the **Reflectometer end** of the 5m rotor test lead. This should be typically less than one ohm, including the resistance of the leads. Note that the loop resistance of the supplied connecting lead set is approximately 0.25 Ohms.

If the measured resistance is greater than one ohm, check the contact resistance between the clip ends of the **brown** and **blue** leads and the field winding. If magnets are being used, remove them and reclean the slip ring and magnet faces if necessary. Record the measured winding resistance.

8. Check the **contact resistance** of the earth magnet to the rotor shaft by measuring the resistance between the **green banana plug** at the **Reflectometer end** and a **point on the rotor shaft** near the magnet. If the resistance exceeds one ohm, reclean the shaft and the magnet face and repeat until a low contact resistance is obtained.

9. Using a low-voltage electrical test meter, measure the **insulation resistance** of the rotor between either one of the the red or blue banana plugs and the green banana plug. A healthy rotor will have an insulation resistance in excess of 1MΩ, although if the winding is damp, this may be reduced to 10KΩ or less. Record the insulation resistance.

10. Record the measured rotor winding resistance **Rw** Ohms and the insulation resistance **Ri** Ohms.

10.4 SETTING UP THE TEST EQUIPMENT

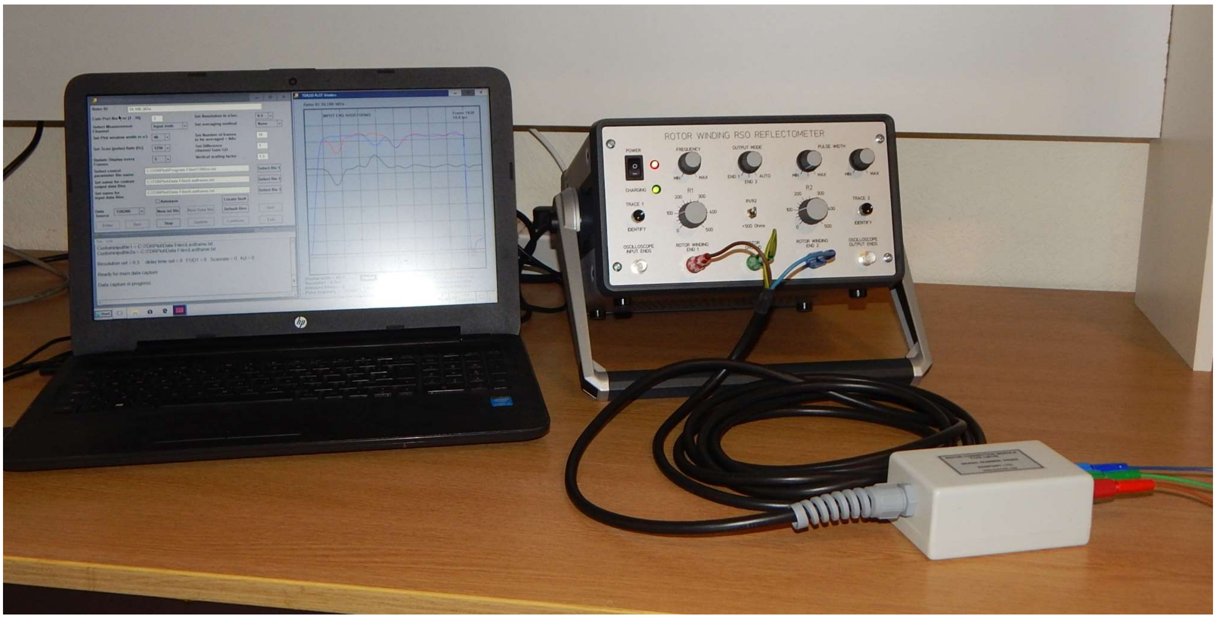


Figure 10.4 TDR200 system with connection module

Connect the rotor winding to the **TDR200 using**, **the long connection lead and connection module** as described in the previous section.

Now connect the **red and blue** plugs of the **5m test lead** to the same colour terminals on the **Reflectometer front panel** (slip ring 1 and 2 terminals) and connect the **green** plug to the **green** earth terminal on the Reflectometer

The overall connection diagrams for operation in **digital mode** is shown in figure 10.5 and **in analogue** mode in figure 10.6.

Note that the delay line is not used for measurements on rotors. It is intended for use for demonstration and calibration check purposes only.

Section 11 gives detailed step-by-step instructions for carrying out an **RSO test** with the **TDR200** unit in **digita**l mode.

Once the RSO test has been completed, the results should be recorded as described in **section 11.11.**

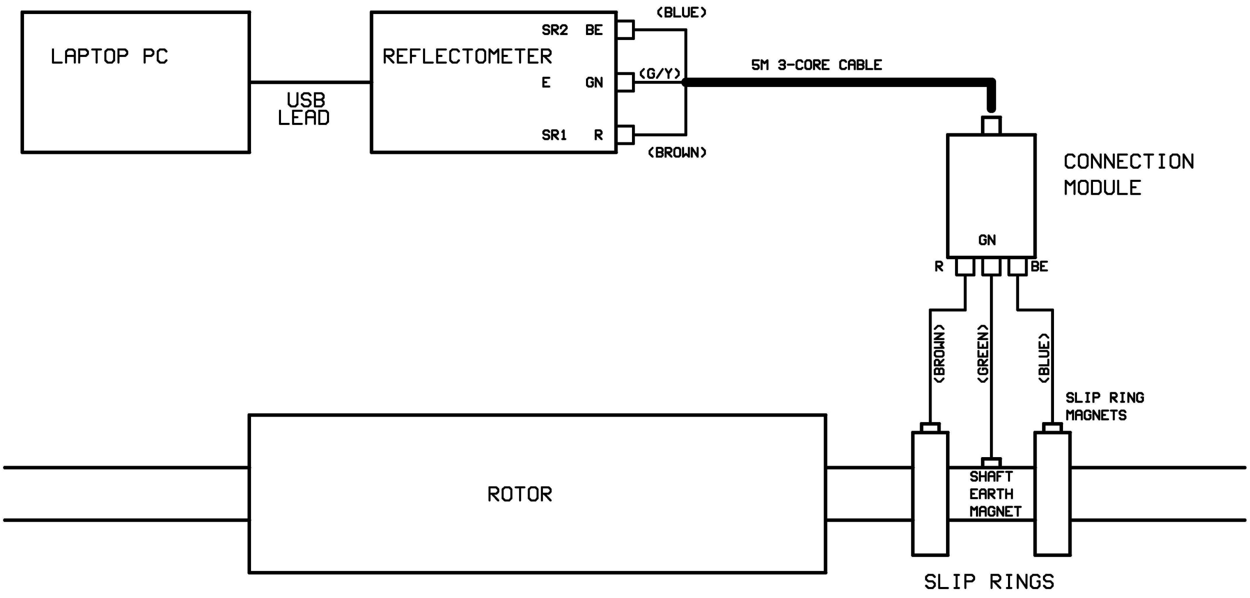


Figure 10.5 Connection diagram for PC digital control mode

In analogue mode, the equivalent connection diagram is shown in figure 10.5.

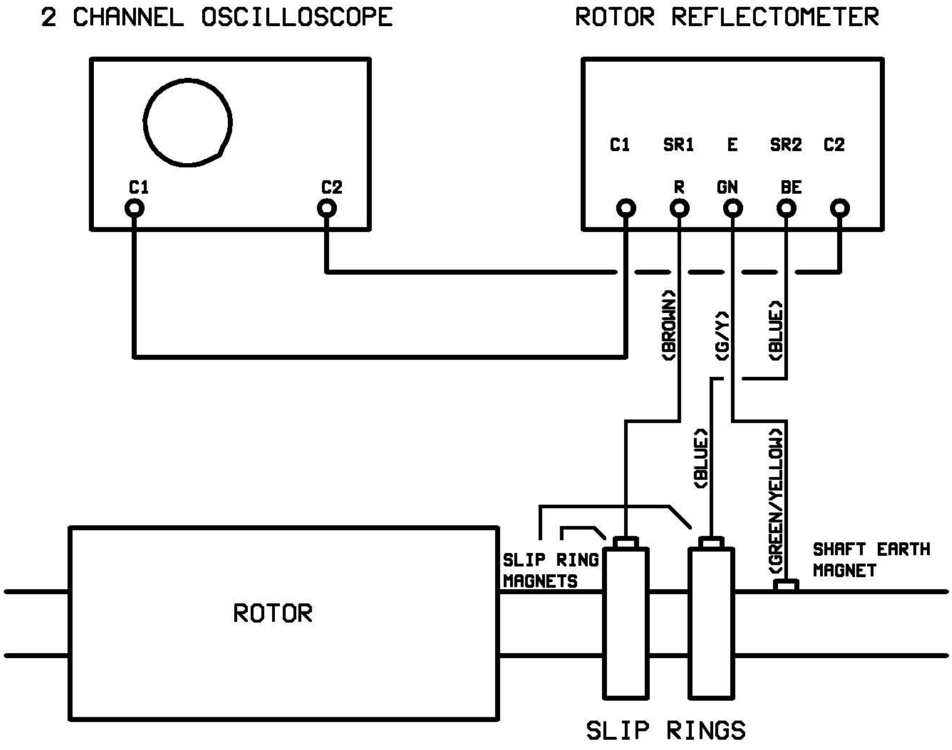


Figure 10.6 Connection diagram for analogue mode

11. TESTING A ROTOR AT REST IN DIGITAL MODE

11.1 OVERVIEW

Before any **RSO tests** can be carried out on a **rotor whose parameters are unknown**, some **preliminary measurements** must first be made to to determine the **single-pass transit time t1** and the **characteristic impedance Z0** of the rotor winding. This is done by adjusting some of the parameters in the **TDRPlot** software and also some of the C**ontrol settings** on the **Reflectometer front panel**.

In principle, **t1** is measured by monitoring the **output end RSO waveforms** and **Z0** is measured by monitoring the **input end waveforms** and adjusting **R2** until there is no reflected pulse from the **output ends**. The details of these measurements are described in the following sections.

11.2 SETTING UP THE TEST SYSTEM

Set up the relectometer measurement system as dscribed in section 10 and connect the **Reflectometer** to the **PC** via the **USB cable** and switch it on. Note that the **USB connector** (printer-type) is on the rear panel of the **TDR200 unit.**

The reflectometer can be operated either from its **internal battery** alone or while the battery is **being charged** from a local mains supply. The **mains supply switch** is on the **rear panel** of the reflectometer and the **battery on/off switch** is located on the **front panel**.

When the PC has booted up, run the **TDRPlot** software by clicking on the **TDRPlot Desktop icon**. The program will run and the **TDRPlot screen** will open. For full details of the **TDRPlot** software operation, please refer back to **sections 5-8**.

11.3 MEASURING THE ROTOR SINGLE-PASS TRANSIT TIME t1

The first task is to measure the approximate time it takes for the input pulse to travel from one end of the rotor winding to the other (**t1**). This information is needed in order to set up the correct control parameters for the software.

11.3.1 SETTING UP THE TDR200 FRONT PANEL CONTROLS

Adjust the front panel controls on the **TDR200** unit as follows:

Frequency: Max **clockwise**
R1 and R2 controls: Set to 100 Ohms
Pulse width switch: middle position
Output mode switch: Auto
Pulse width control: Fully **clockwise** (maximum)

11.3.2 INITIALISING THE PARAMETERS IN THE CONTROL WINDOW

Set the parameters in the **TDRPlot Control Window** as follows:

Rotor ID: Enter a text description for the rotor under test (Max 64 characters)
Com Port Number: The number of the PC com port in use (see **Appendix 1**).
Select Measurement Channel: Output ends
Set Plot window width: 384uS *
Set scan Rate Hz 250
Update Display: 1 frames

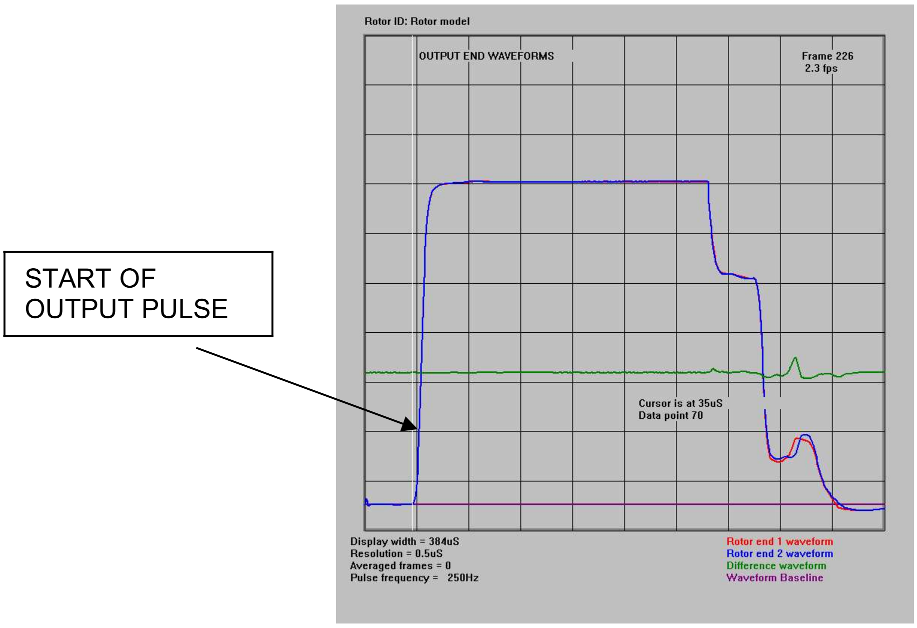
Set resolution : 0.5uS
Set averaging method: None
Set number of frames to be averaged (Nav): 1
Set difference channel gain (GD): 1
Set Vertical Scaling factor = 1.6 (or adjust to suit window height)
Data Source: TDR200 (default)

* The large **display width** is needed initially to ensure that an initial value can be found for **t1**. This will be subsequently modified once t1 is known.

11.3.3 STARTING DATA CAPTURE

Check that the control parameters have been input correctly in the **Control Window** and then click on the **Enter** button. This loads the set parameters into the **TDRPlot** software and the **new control parameters** will be updated in the **Control window**.

Next click on the **Run** button, which starts the data capture (**scanning**) process. The **waveforms at the output ends of the rotor winding** will be displayed in the **Plot window** as shown in figure 11.3.1. All of the results in this section were obtained using the **rotor model** described in **Appendix 3,** which also shows some RSO waveforms for a range of simulated winding faults.


START OF OUTPUT PULSE

Rotor ID: Rotor model

Cursor is at 35uS
Data point 70

Display width = 384uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

Figure 11.3.1. Plot window (output ends)

Temporarily adjust the value of **R1** on the **TDR200** unit so that the height of the trace is approximately 70% of the **plot window height** as shown in figure 11.3.1, then click on the **Pause button** in the **Plot window**, which will stop the scanning. Now click the **mouse pointer** at the point near the start of the output waveforms (where the waveform starts to increase). This will generate a white time cursor line as shown in figure 11.3.1.

The **time at the cursor position** is displayed at the **mouse click** position. Note the time displayed for the cursor (in this case, 35uS). This is the time in microseconds for the pulse to pass through the rotor winding from one end to the other. This is known as the **single-pass transit time (t1)**.

Now that the **approximate single-pass transit time t1** is known, the **Control parameters** can be optimised.

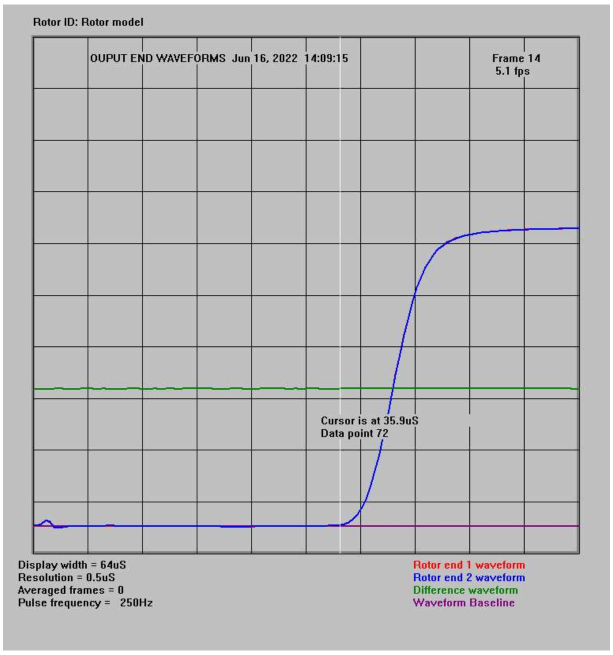
11.4 OPTIMISING THE CONTROL PARAMETERS.

11.4.1 Optimising the transit time measurement

Adjust the **Plot width** to have a value around **2 x t1**. This is done as follows:

Click on the **Pause** button to stop the scanning and modify the **Plot width** parameter in the **Control window** to give a **Plot window width** around 2 **x t1 (**in this case, 2*35 = 70. Note that the **Plot window width** is always a **multiple of 16uS**, so choose a value for the **Plot width** parameter which approximates to this value (in this case, 64uS)

Resume scanning by clicking on the **Update** button to set the new **plot width** value and then click on the **Continue** button. An updated plot window for the **output end** waveforms will be displayed as shown in figure 11.4.1 below:



Cursor is at 35.9uS
Data point 72

Display width = 64uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

11.4.1 Optimised Plot window (output ends)

Click on the **Pause button** and then use the **mouse cursor** to obtain a more accurate estimate of **t1 (35.9uS)** and **record this value**.

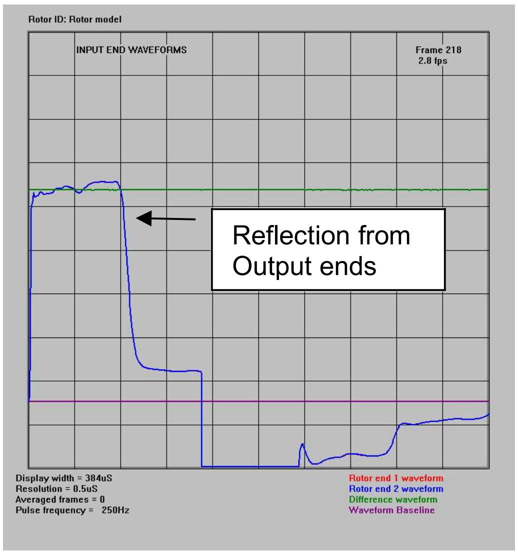
11.4.2 Optimising the impedance matching values of R1 and R2

Now click again on the **Pause button** and set the **Measurement channel** box in the **Control window** to display the **input end** waveforms.

Temporarily, reset the **Plot window width** to **384uS** and set the value of **R2 to zero.**

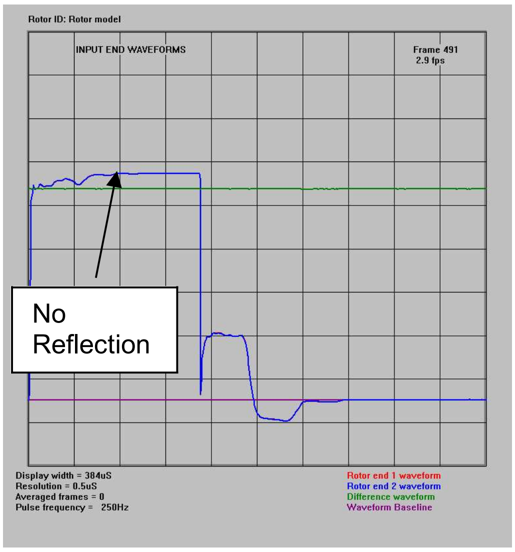
Click the **Update** button in the **Control window** and then the **Continue** button to display the **input end** waveforms as shown in figure 11.4.2.

By deliberately mis-matching the **output end terminating impedance control (R2)** on the **TDR200** unit, it is now possible to see where the reflections from the winding ends start and to measure this time using the **Cursor** facility.



Display width = 384uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

Figure 11.4.2 Initial input end waveforms

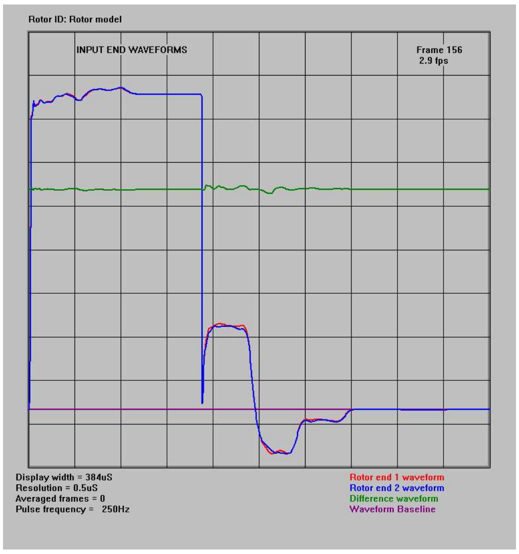


Display width = 384uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

Figure 11.4.3 Matched input end waveforms

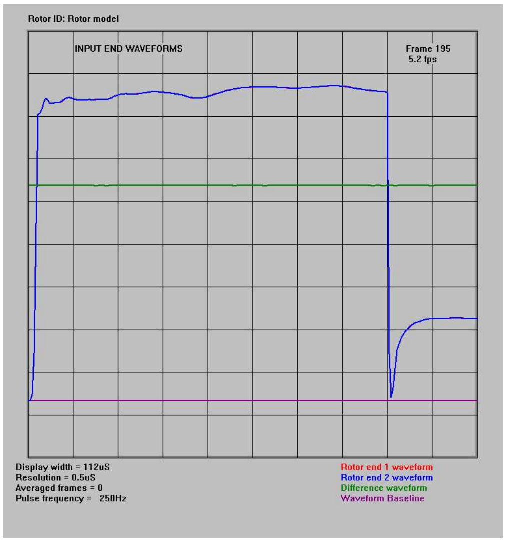
Now adjust the value of **R2** on the **TDR200** unit to minimise the reflection from the ends of the rotor windings as shown in figure 11.4.3.

Next, set the value of **R1** equal to this value of **R2**. The resulting waveforms should ressemble those in figure 11.4.4



Display width = 384uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

Figure 11.4.4 Matched values of R1 and R2



Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 250Hz

Figure 11.4.5 Final input end waveforms with optimised display width

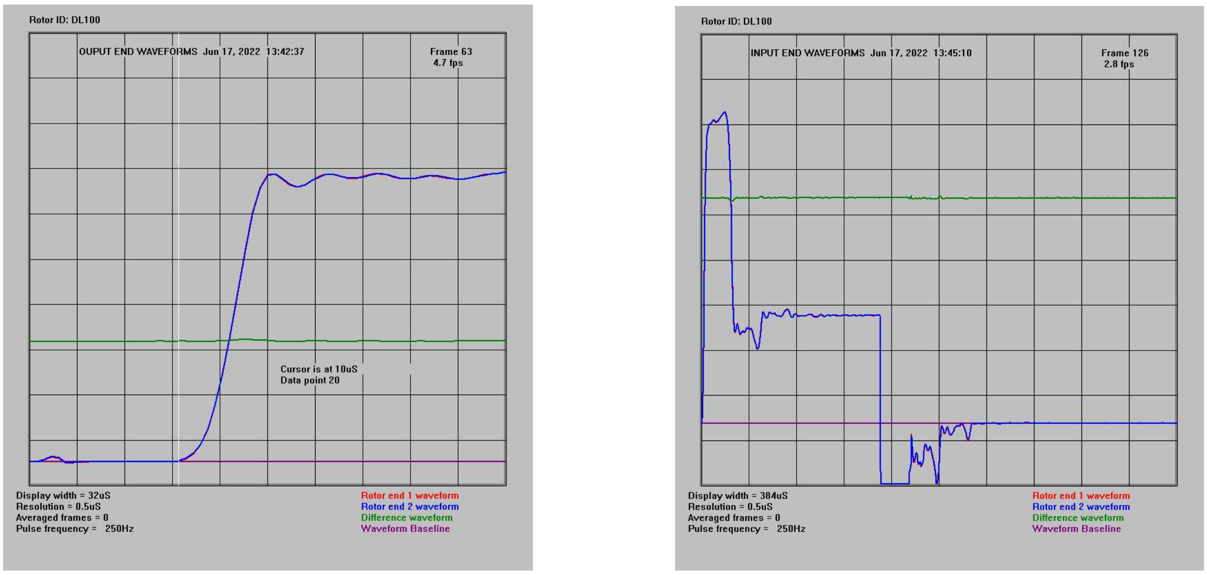
Finally, set the **Plot window width** to approximately **3 x t1 (112uS) in the Control window** and resume scanning. Adjust the **pulse width** controls so that the waveforms are similar to those shown in figure 11.4.5. These are the **RSO results** which would be expected for a **fault-free rotor winding** under **impedance-matched** conditions.

Record the values for **R1/R2**, **t1** and the **plot width setting** (112uS) for later use.

Now set the scan (pulse) rate to **1250 fps** in the **Control window** and check that the **RSO waveforms** are similar to those captured at **250 fps**. If this is not the case, reduce the frame rate until the waveforms are similar to those at 250 fps. The **highest scan pulse rate** which does not change the overall shape of the measured waveforms should be used for all subsequent measurements.

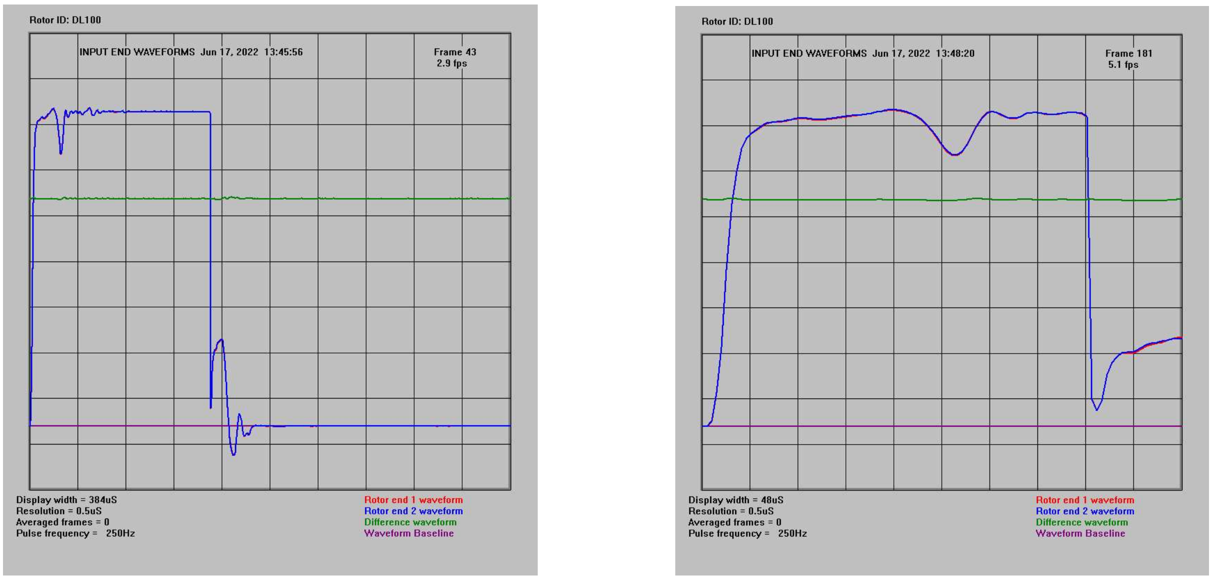
11.4.3 EQUIVALENT RSO WAVEFORMS USING DL100 DELAY LINE

The following wavforms were obtained by using the above instructions with the **DL100 delay line** instead of the rotor model.



(a) Output end waveforms

(b) Input end waveforms R2 = 0



(c) Input end waveforms R2 matched to Z0

(d) Optimised input end waveforms

Figure 11.4.6 Equivalent waveforms for DL100 delay line

11.5 INTERPRETING THE RSO WAVEFORMS

Detailed information about how to interpret the **RSO waveforms** is given in section 12 of the **TDR200 Reference Manual**

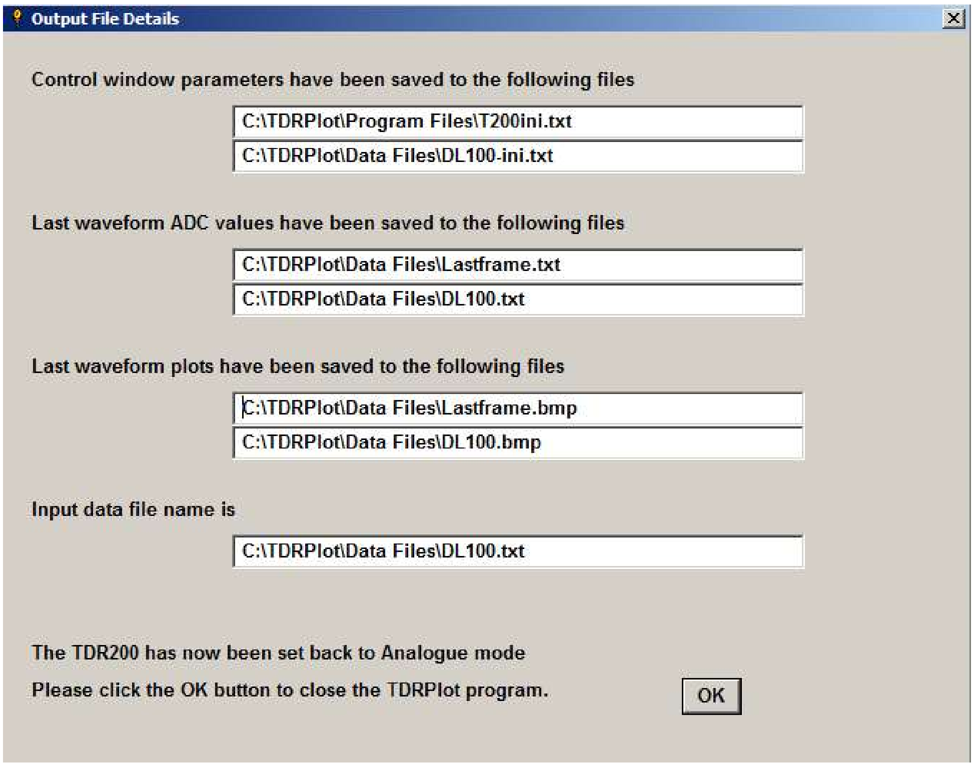
A normal fault-free rotor winding is characterised by 2 identical waveforms at each end of the rotor winding (**red** and **blue** waveforms) with a horizontal straight line (**green**) difference waveform, as shown in figure 11.4.2.

11.6 EXITING THE SOFTWARE

To exit the software before scanning has started, click on the **QUIT** button in the **Control window**.

To exit the program after the **Enter button** has been clicked, click the **EXIT** button in the **Control** window

This operation generates a number of files containing the last frame of ADC data and also a copy of the **Plot window** in bitmap format as described in section 8. An **Output File Details window** is also generated as shown in figure 11.6.1.



Control window parameters have been saved to the following files

C:\TDRPlot\Program Files\T200ini.txt
C:\TDRPlot\Data Files\DL100-ini.txt

Last waveform ADC values have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.txt
C:\TDRPlot\Data Files\DL100.txt

Last waveform plots have been saved to the following files

C:\TDRPlot\Data Files\Lastframe.bmp
C:\TDRPlot\Data Files\DL100.bmp

Input data file name is

C:\TDRPlot\Data Files\DL100.txt

The TDR200 has now been set back to Analogue mode

Please click the OK button to close the TDRPlot program.

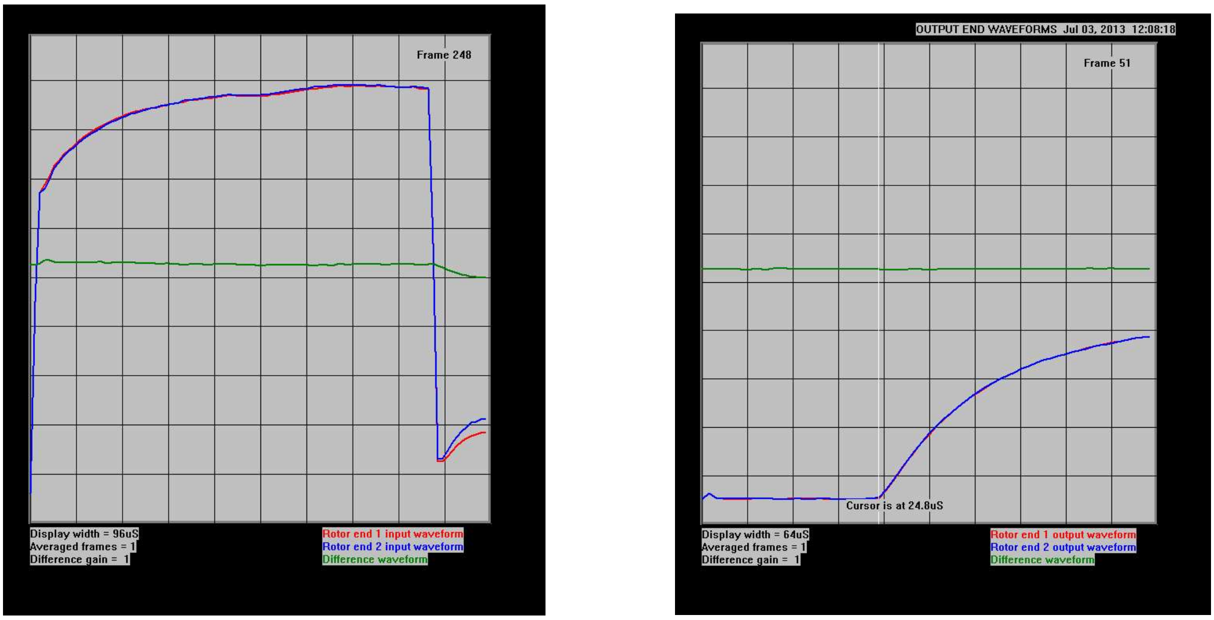
Figure 11.6.1 Output File Details window

Note that if the **Both ends** option is selected in the **Control** window on exit, the **waveform (.bmp)** image files will contain the correct image. However the **Data (.txt)** file will contain only the data for the **input end** waveforms.

11.7 SAMPLE RSO TEST RESULTS FROM A 660 MW 2-POLE ROTOR

The next few sections contain some examples of RSO waveforms obtained from a 2-pole 660 MW rotor during repairs at a manufacturer's works.

11.8 RSO WAVEFORMS FOR A FAULT-FREE ROTOR WINDING



Display width = 96uS
Averaged frames = 1
Difference gain = 1

Cursor is at 24.8uS
Display width = 64uS
Averaged frames = 1
Difference gain = 1

11.8.1 Input end waveforms **11.8.2 Output end waveforms**

FIGURE 11.8 RSO WAVEFORMS FOR A FAULT-FREE 660 MW ROTOR

These **RSO waveforms** were obtained for a **fault-free** rotor tested prior to its replacement in the generator.

Note the two identical end1 (**red)** and end 2 (**blue**) waveforms and the horizontal (**green)** difference waveform obtained for the input end waveforms in figure 11.8.2.

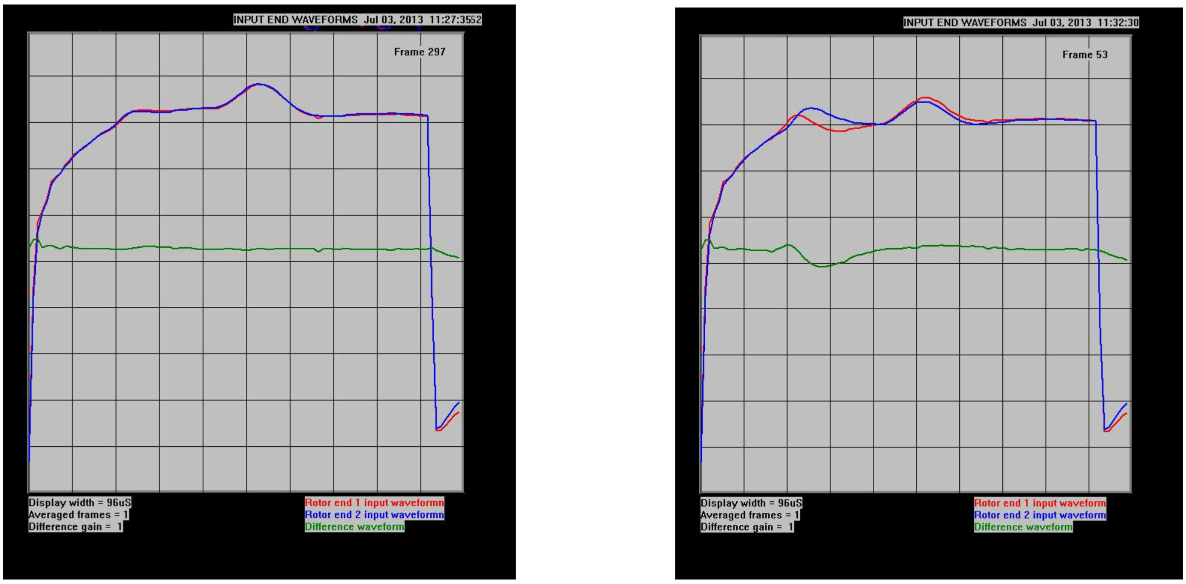
Figure 11.8.2 shows the **output end** waveforms for the same rotor. It also shows the use of the **cursor** button to measure the **single-pass transit time** (in this case 24.8uS) of the rotor winding.

These are typical RSO results for a healthy rotor winding.

The results in the next section were obtained from the same 660MW rotor winding during repair.

One end-ring had been **removed**, which allowed simulated faults to be applied to the **half-winding** connected to **the end 1** slip ring (**red** waveforms)..

11.9 RSO RESULTS FOR A ROTOR WINDING DURING REPAIR



11.9.1 Fault-free winding

(1 end ring removed)

11.9.2 rotor with simulated interturn fault
(1 end ring removed)

RSO WAVEFORMS FOR ROTOR WITH END RING REMOVED

With one end ring removed, the characteristic impedance of the rotor winding changes in the **end regions** of the winding.

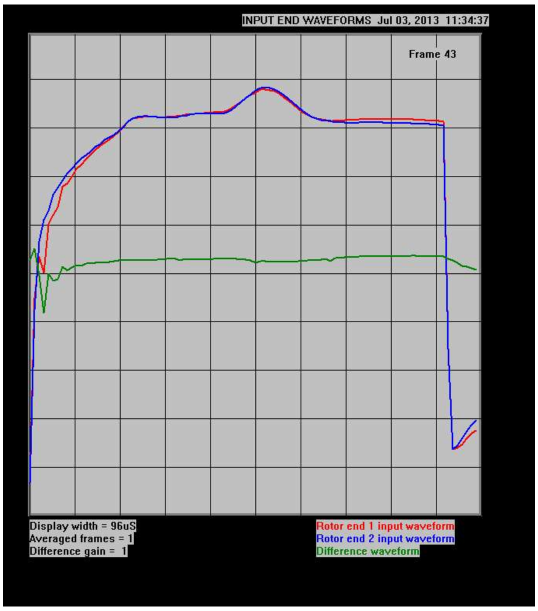
This causes a **peak** in the **input end waveforms** as shown in figure 11.9.1 above. However, note that both the red and **blue** waveforms remain identical as there is **no winding fault**.

Figure 11.9.2 shows the RSO results obtained from the same rotor rotor where an entire coil in the winding had ben shorted out.

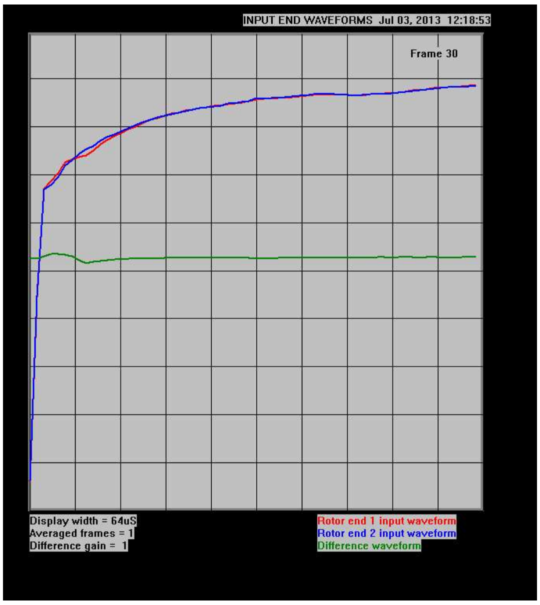
Shorting out a complete set of windings in a slot coil causes a characteristic loop to appear between the **red** and **blue** waveforms.

Note that the applied fault is nearest to the end 1 (**red** waveform) and that the **red** waveform first increases, then decreases at the fault location.

The following sections show the results of applying a single interturn fault and also an earth fault to this rotor winding.



11.9.3 Rotor with a single shorted turn applied to first coil from end 1 (1 end ring removed)



11.9.4 rotor with a single shorted turn applied to third coil from end 1 (both end rings in situ)

INPUT END WAVEFORMS WITH 1 SHORTED TURN APPLIED TO FIRST COIL FROM END 1 SLIP RING

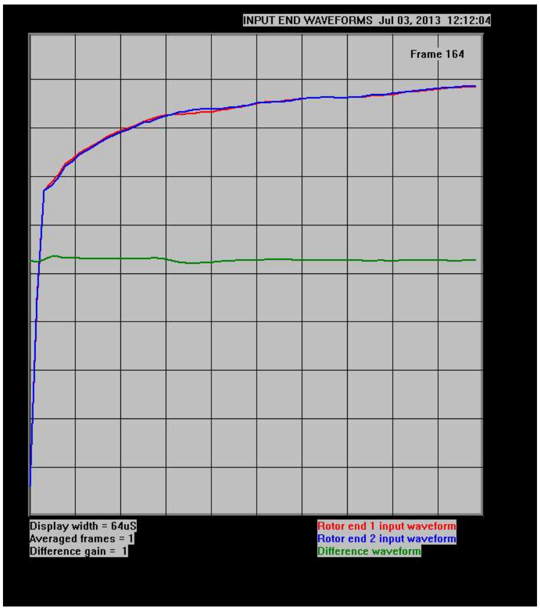
The effect of shorting out a single turn produces a **maximum difference** in the input end waveforms when the shorted turn is close to the **start** of the winding as shown in figure 11.9.3 above for the rotor with one end ring removed..

All of the remaining results in this and the following figures were obtained by shorting the turns with **2 insulated probes** connected by a short length of insulated wire**.** The rotor **winding turns** were accessed by inserting the probes into radial cooling holes in the rotor slots and holding the probe ends against the sides of the rotor conductors.

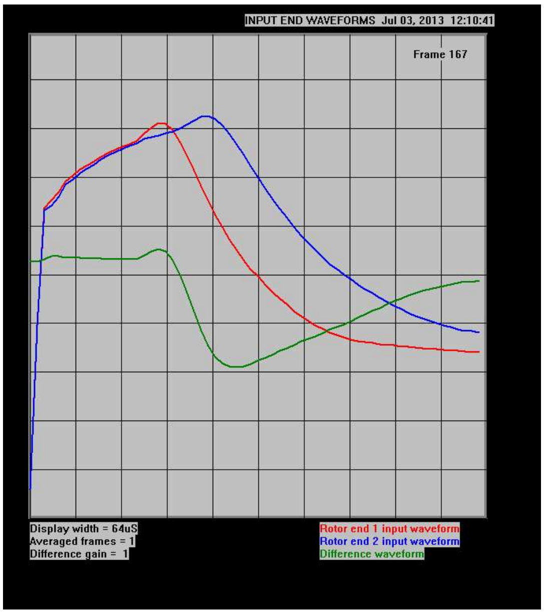
However, the relatively **high impedance** of this wire link at the RSO pulse frequencies reduces **the sensitivity of the RSO test** but still demonstrates the principle .

A real short or the use of eg a U-shaped metal shorting link will give a bigger response.

As the location of the fault is moved towards the centre of the winding, the measurement sensitivity decreases as shown in figure 11.9.4 above.



11.9.5 Rotor with a single shorted turn applied to 8th (last) coil from end 1 (both end rings in situ)



11.9.6 Rotor with a single earth fault applied to 8th (last) coil from end 1 (both end rings in situ)

INTERTURN AND EARTH FAULTS APPLIED TO 8TH COIL IN END 1 HALF-WINDING

Figure 11.9.5 shows that although the measurement sensitivity has decreased, it is still possible to detect a shorted turn close to the centre of the rotor winding.

An earth fault is easily detected and located using the RSO test. In this case, a short to ground has been applied to the half-winding closest to end 1 (red waveform).

11.10 OUTPUT FILE MANAGEMENT

The **output data files** generated by the **TDRPlot** software will be in the **Data Files** subfolder in the **Default** folder.

Once a test has been completed, we suggest that **a new folder** should be created with a unique name which identifies the rotor under test.

The files in the **Data Files** subfolder should then be moved to this new folder for safe keeping.

11.11 RECORDING THE RSO TEST RESULTS

11.11.1 USING A WORD TEMPLATE

Figure 11.9 suggests one possible format for recording the test results which includes the resistance measurements described in **section 10.3.**

A blank template for this document is given in **Appendix 2** and is also included as an **MS Word document** in the **TDRPLot** software supplied with each **TDR200 system**.

11.11.2 AS DIGITAL FILES

The input and output end waveforms shown in **section 11.8** should be saved to both **.bmp** (bitmap) and **.txt** (text) files having unique file names which allow the rotor to be identified. This will happen automatically if the Rotor ID has been entered correctly in the **TDRPlot Control window** and the **Save** button has been used in the **Plot window**.

These files should then be copied to a **unique folder** on the PC and transferred to a suitable PC filing system for future reference, along with the **Word results file**.

ROTOR WINDING RSO TEST REPORT

LOCATION: Wilmslow PS

TEST DATE: 1-1-1999

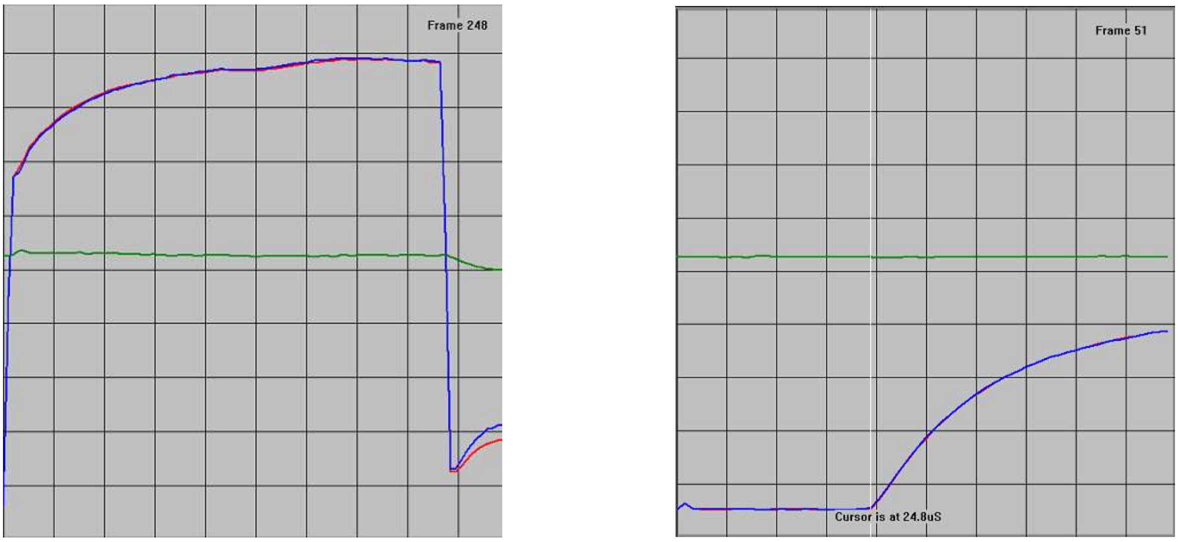
ROTOR TYPE: Cylindrical

RATING MW: 500MW

MANUFACTURER: GEC

DATE OF MANUFACTURE: 1966

NUMBER OF POLES: 2



(a) Input end waveforms

(b) Output end waveforms

EXCITATION METHOD: SLIP RINGS? ✓ ROTATING RECTIFIER?

TEST CONDITIONS
IN STATOR ✓ AT REST ✓ AT SPEED REMOVED FROM STATOR

END RINGS: IN SITU ✓ REMOVED

MEASURED WINDING RESISTANCE: 0.4 OHMS
MEASURED INSULATION RESISTANCE: 1.5 M OHMS

SINGLE-PASS TRANSIT TIME (FROM OUTPUT END WAVEFORMS) T1 24.8 uS:
DOUBLE-PASS TRANSIT TIME (FROM INPUT END WAVEFORMS) T2 51 uS:

COMMENTS ON TEST RESULTS

No winding faults detected

FIGURE 11.9 ROTOR RSO TEST REPORT

11.12. DEALING WITH ELECTRICAL NOISE AND INTERFERENCE

It is likely that the **TDR200 equipment** will be operated in areas where there is a high level of electrical noise and interference, which can adversely affect the operation of many types of sensitive electronic measurement equipment.

The most likely effect of high noise levels is disruption to the running of the **TDRPlot software**. If this occurs, the simplest solution is to exit and restart the software.

One common path for electrical noise to enter the equipment is via the mains supply. If interference problems are encountered, it may be possible to eliminate them by running both the **Laptop PC** and **TDR200** unit on **battery power only**.

11.13 COMPENSATING THE PC DISPLAY FOR VARIATIONS IN BATTERY VOLTAGE.

The amplitude of the excitation signal applied to the rotor varies with the state of charge of the internal 12V battery and may affect the position of the RSO traces on the PC screen.

If necessary, compensate for this effect by changing the **Vertical scaling factor** in the PC **Control Window**. Suitable scaling factor values are 1.5 for a fully-charged battery and 1.6 for a partially-discharged battery.

Small variations in the vertical position of the RSO waveforms can also be made by adjusting the **R1 Input end impedance matching control** on the **front panel** of the **TDR200** unit.

12. METHOD FOR TESTING A ROTOR AT REST WHILE INSTALLED IN THE GENERATOR IN ANALOGUE MODE

A similar technique to that described in section 6 is used for testing a stationary rotor **in analogue** mode, including compliance with the **SAFETY WARNING**. The following instructions assume the use of a conventional **analogue** oscilloscope. Information about using a **digital oscilloscope** is given in section 12.5.

12.1 SET UP THE MEASUREMENT SYSTEM CONNECTIONS

1. Follow all of the steps described in section 10. to connect the **TDR200** unit to the rotor winding.

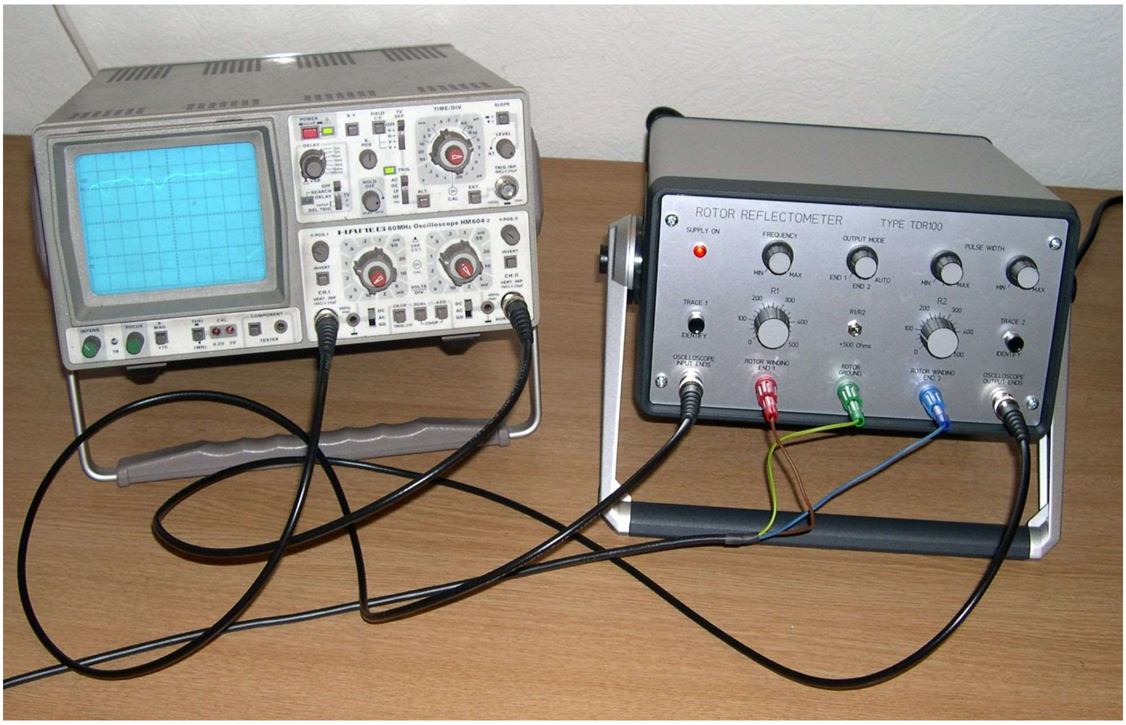


Figure 12.1. Measurement system connectivity in analogue mode

2. Connect the coaxial **BNC Oscilloscope leads,** shown in figure **figure 12.2** from the **oscilloscope input channel type BNC terminals** to the **reflectometer oscilloscope BNC terminals** as follows:

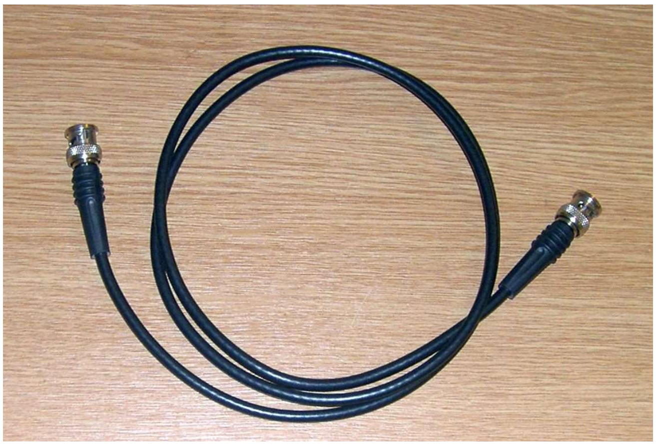


Figure 12.2. Oscilloscope Lead

3. Connect one coaxial lead between the **oscilloscope channel 1 input** and the **reflectometer oscilloscope input ends connector**. Turn the BNC connector on the coaxial lead clockwise to lock it into position.

4. Similarly, connect the other coaxial lead between the **oscilloscope channel 2 input** and the **reflectometer oscilloscope output ends connector**.

The system connectivity should now be as shown in figure 10.6 and repeated here for convenience.

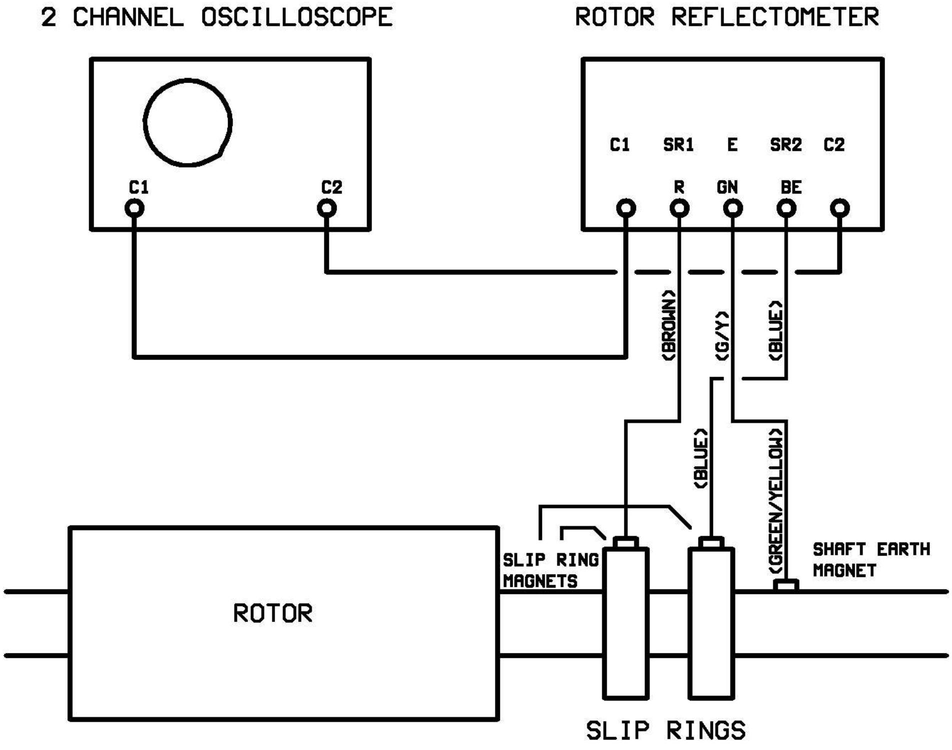


Figure 10.6 Connection diagram for analogue mode

12.2 SET UP THE TDR200 AND OSCILLOSCOPE CONTROLS

1. Set the controls on the **Reflectometer** initially as follows:

R1= R2 = 100Ω

PULSE FREQUENCY : Fully clockwise
PULSE WIDTH SWITCH : Centre position
PULSE WIDTH POTENTIOMETER : Mid scale
PULSE OUTPUT SWITCH : Auto
R1/2 TOGGLE SWITCH : Up (0 - 500 Ohms)

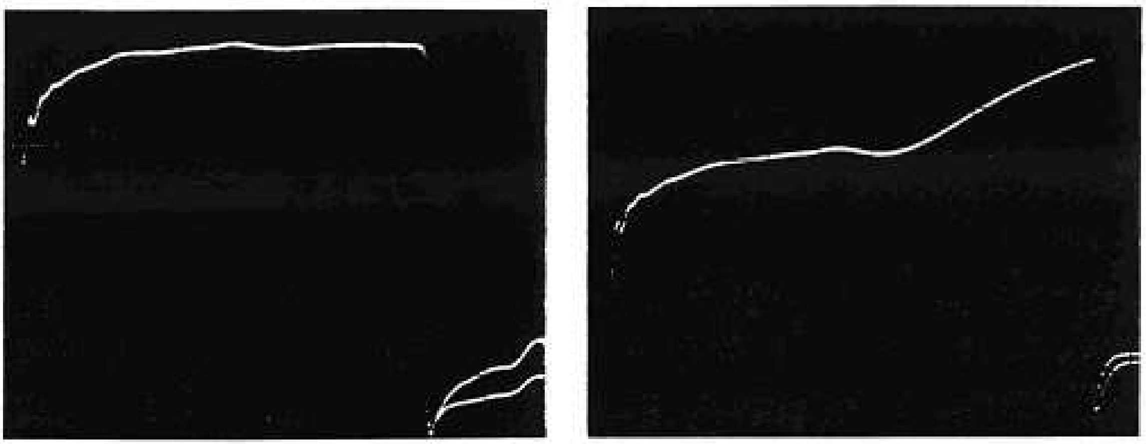
2. Set the oscilloscope controls initially as follows:

DISPLAY : Channel 1
VERTICAL SENSITIVITY : 2V/CM (Both channels)
TRIGGER CONTROLS
- MODE : Normal
- SOURCE : Channel 1
- LEVEL : Positive
- SLOPE : Positive
- COUPLING : D.C.
- TIME BASE : 20 μsec/CM

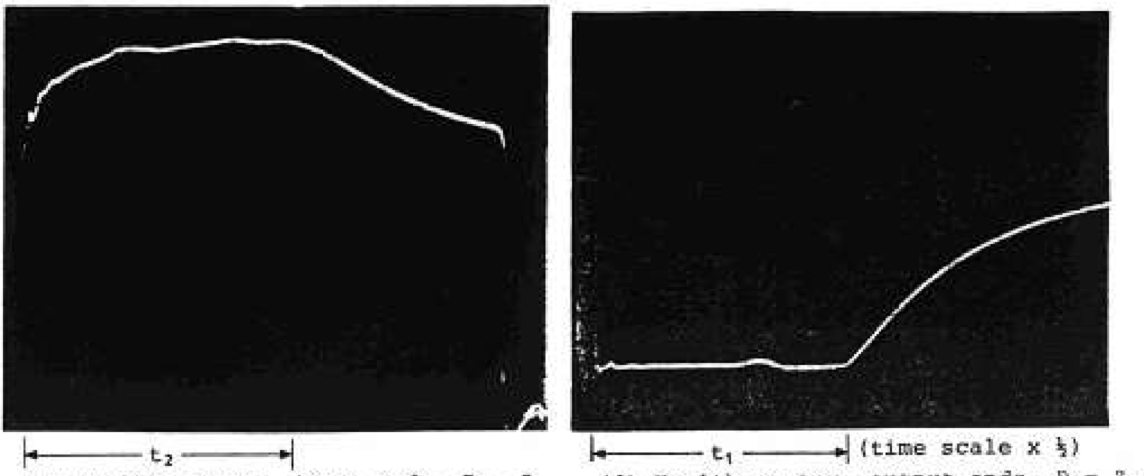
12.3 VIEW AND CAPTURE THE RSO WAVEFORMS

1. Switch on the **Oscilloscope** and the **Reflectometer**. Adjust the oscilloscope trace position and triggering controls until a stable pulse is displayed on the oscilloscope screen. This is the waveform at the input ends of the rotor winding and should resemble one of the traces shown in Fig. 12.3 (a) to (c).

Further detailed information about these waveforms is given in section 1.



(a) Healthy rotor, input ends, $R_2 = Z_0$ (b) Healthy rotor, input ends, $R_2 = \infty$



(c) Healthy rotor, input ends, $R_2 = 0$ (d) Healthy rotor, output ends, $R_2 = Z_0$

Figure 12.3 Typical oscilloscope waveforms

2. Switch the **oscilloscope to display channel 2** or, if a single channel oscilloscope only is available, connect the oscilloscope input lead to the '**OSCILLOSCOPE OUTPUT END**' terminal of the **Reflectometer**. Adjust the oscilloscope controls until a trace similar to that shown in Fig. 12.3(d) is obtained. This trace shows the pulse received at **each remote end** of the rotor winding. Adjust the oscilloscope timebase switch (and, if necessary, the Reflectometer pulse width controls) until the single pass transit time [t_1 in Fig. 12.31 (d)] occupies less than half of the trace width. Record this transit time in micro-seconds.

3. Switch the oscilloscope back to **display channel 1** and adjust the **pulse width controls** on the Reflectometer unit so that the trailing edge of the pulse be seen at the far right of the trace as shown in Figs. 12.3 (a) to (c). This is a convenient way of displaying the **zero voltage level**. Now **adjust R2** so that there is no reflected signal from the ends of the winding.

Fig. 12.3 shows three cases:

a)	R2 matched	(no reflection)
b)	R2 too large	(positive reflection)
c)	R2 too small	(negative reflection)

The reflection is seen at the input ends t_2 seconds after the start of the pulse, where t_2 is approximately twice the single pass transit time (t_1).

Note that the range of the **Matching Resistors R1 and R2** can be increased using the **R1/R2** switch.

If the switch is in the **UP** position, the range is 0 - 500 Ohms.

If the switch is in the **DOWN** position, the range is 500 - 1000 Ohms.

If the toggle switch is down when correctly matched, add 500Ω to the dial reading to obtain the value of R1/R2.

4. Having matched the output ends correctly, **note the value of R2** (adding 500Ω if necessary), which is the average **characteristic wave impedance** of the rotor winding. **Now set R1 = R2 to complete the matching at the input ends**. This eliminates the possibility of multiple reflections from one end of the rotor to the other. It may now be necessary to adjust the oscilloscope vertical sensitivity controls to optimise the trace size relative to that of the oscilloscope screen.

5. If the rotor winding is perfect, **two perfectly superimposed traces** will be displayed on the screen. If this occurs then the rotor winding can be safely assumed to be fault-free. To verify the existence of the two traces, push one of the **trace identifier** buttons, when one of the traces should be displaced vertically towards the zero voltage level, showing the two traces. If only one trace is displayed check that the **PULSE OUTPUT** mode switch is in the **AUTO** position.

6. If two perfectly superimposed traces are not obtained, there may be a fault in the rotor winding. Section 11.9 explains in detail the trace shapes to be expected for various types of faults.

7. Record the traces by photographing the oscilloscope display using a digital camera (with the flash turned off), then edit the image using an image editing program such as the freeware **Irfanview**, available from: **http://www.irfanview.com/**

An example of a screenshot obtained using this method is shown in figure below.

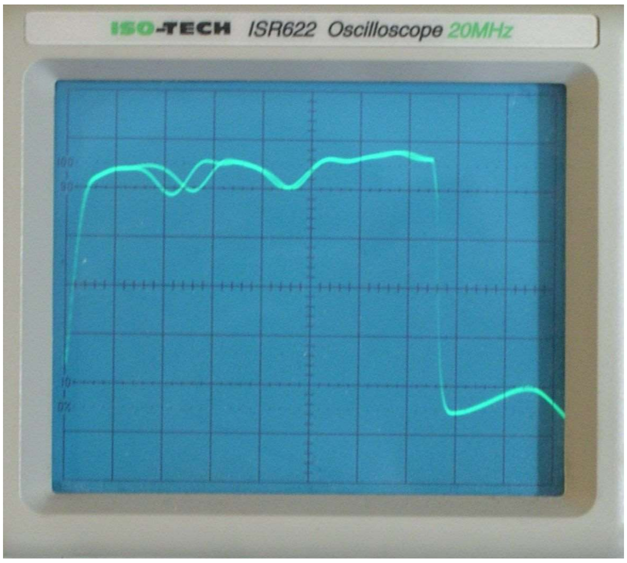


Figure 12.4 Screenshot of traces for Delay line with simulated interturn fault.

12.4 ADDITIONAL OPERATING MODES

In addition to operation in **Auto mode**, it is possible to apply pulses to either slip ring 1 or slip ring 2 only. This option can be useful when using a digital oscilloscope to monitor the traces as described in **section 12.5**. The operating mode is controlled by the 3-way **Pulse Operation switch** as follows:

Position 'END1' - pulses are injected into slip ring 1 only.
Position 'END2' - pulses are injected into slip ring 2 only.
Position 'AUTO' - normal operating mode. (Pulses injected at alternate ends)

12.4.1 Output Mode switch

For normal rotor testing ensure that this switch is in the '**AUTO**' position, as the single trace produced when the switch is in the '**END1**' of '**END2**' position will not indicate a winding fault.

When in the '**AUTO**' position always check that two traces are present by using the '**Trace Identify**' buttons. If only one trace is shown when one button is pressed, check and adjust the triggering of the oscilloscope (particularly when using a digital oscilloscope).

12.5. USE OF DIGITAL OSCILLOSCOPES

In principle, it is possible to use a **digital** oscilloscope instead of an **analogue** instrument to display the **RSO** waveforms. However, most budget digital oscilloscopes have limitations which may prevent them from being used effectively with **TDR200** reflectometers. This section describes some possible ways for coping with these limitations.

12.5.1 OVERVIEW

One of the main uses of the **TDR200** measurement system is to display live waveforms during a winding repair, so that the winding state can be monitored continuously and the onset or clearance of faults seen immediately. To do this, the oscilloscope must display simultaneously the two waveforms corresponding to pulse injection from each end of the rotor winding.

In its normal (**Auto**) mode of operation, the **TDR200** produces alternating waveforms at the input to one oscilloscope channel corresponding to the pulses injected from each end of the rotor winding. To view them correctly, the oscilloscope must trigger on the leading edge of each alternating pulse waveform. Most **analogue oscilloscopes** can do this routinely. However, many **digital oscilloscopes** have difficulty displaying signals where successive waveforms are different.

Digital oscilloscopes often use some form of **waveform averaging** to reduce the noise on the displayed traces but if this is used, only one of the waveforms can be shown at any single time. Although averaging can usually be turned off, the result is waveforms with a high level of superimposed **noise.** Even with averaging disabled, the osciloscope triggering may still be unable to track the alternating waveforms produced by the **TDR200** equipment.

A number of options are available to overcome some of these problems and these are described in the following sections.

The instructions given are based on the use of the **Tektronix TDS 1000/2000** oscilloscope equipment range and should be modified accordingly for other oscilloscope models.

12.5.2 OPTION 1. USE OF AUTO MODE

It may be possible to use the **TDR200 Auto mode** in the same way as described for an **analogue oscilloscope**, by careful adjustment of the **Frequency** control on the **TDR200** unit. We suggest that familiarity with the technique is gained using the demonstration **delay line** initially, as described below:

Apply a shorting link between terminals 5 and 6 of the delay line to simulate an interturn fault and connect the delay line to the **TDR200** system as described in **section 3**.

Connect **channel 1** of the oscilloscope to the **TDR200 input end oscilloscope BNC connector** and set the **reflectometer controls** as described in **section 3**. Then set **channel 1** to display the **input end waveforms**, as shown in figure 12.5.1.

Figure 12.5.1 Digital oscilloscope waveforms at input ends using delay line with simulated inter-turn fault

The following comments (applicable to Tektronix TDS 1000/2000 series) may be helpful in setting up the oscilloscope initially:

Press the **Acquire** button and select **Sample** from the **ACQUIRE** screen.

If necessary, disable all other channels by pressing the appropriate **channel select buttons** until all traces other than that for **channel 1** are no longer displayed.

Press the **Trig Menu** button and set the **trigger controls** as follows:

Type: edge

Source: CH1

Slope: rising

Mode: normal

Coupling: DC

Now adjust the **trigger level** control until reliable triggerring occurs.

Move the **channel 1 baseline** to +1 horizontal graticule line from the bottom of the screen using the **channel 1 offset control knob**.

Adjust the **maximum waveform amplitude** to + 7 graticule lines from the bottom of the screen using the **channel 1 gain control knob**.

Expand the **horizontal time scale** to show all of the waveform using the **horizontal sec/div control knob**.

Move the **start of the waveform** to the +1 vetrical graticule line using the **horizontal position control knob**.

Adjust the **frequency control** on the **TDR200** unit until 2 waveforms are displayed as shown above.

Using this technique, the **2 input end waveforms** can be displayed and compared directly and continuously. However, in the case of the TDS oscilloscope range, these 2 waveforms cannot be saved directly, as the **save image** function apears to save one of the individual waveforms, not the displayed image. It is also not possible to reduce the image noise by averaging in this option.

12.5.3 OPTION 2. USING THE SINGLE END INJECTION MODE TO CAPTURE THE WAVEFORMS

As an alternative to **alternating end pulse injection**, the **TDR200** unit can inject pulses at one end of the rotor winding only.

If this is done sequentially at each slip ring, it is then possible to use the digital oscilloscope to capture and store these two waveforms in internal memory and then compare them.

The advantage of this method is that it is possible to save the two measured waveforms as .bmp files directly to a **USB memory stick**. It is also possible to reduce the noise levels in the images using the averaging option

This can be carried out as follows:

Connect the **TDR oscilloscope input ends connector** to the **Oscilloscope input channel 1**.

Press the **ACQUIRE** button on the oscilloscope and set the screen options to Average 16 samples.

Set the **TDR200 mode switch** to **END1** (Inject pulse at **slip ring 1** only).

Capture and save the Slip ring 1 (end1) waveform as follows:

Press the **SAVE/RECALL** button on the oscilloscope and set the screen options to:

Action: **Save waveform**
Save to: **Ref**
Source: **Channel 1**
To: **Ref A**

Press the (on-screen) **Save** button

The **end1 input waveform** will be saved to **Reference A** in the oscilloscope memory.

The next step is to capture and save the Slip ring 2 (end2) waveforms

Set the **TDR200 mode switch** to **END2** (Inject pulse at slip ring 2 only).

Press the **SAVE/RECALL** button on the oscilloscope and set the screen options to:

Action: **Save waveform**
Save to: **Ref**
Source: **Channel 1**
To: **Ref B**

Press the (on-screen) **Save** button

The **end2 input waveform** will be saved to **Reference B** in the oscilloscope memory.

View the 2 waveforms

Press the **Channel 1 menu button** to switch off the live channel 1 display.

Press the (white) **REF MENU** button on the oscilloscope

Use the (on-screen) buttons to turn on (display) the stored **Ref A** and **Ref B waveforms** as shown in the figure below:.

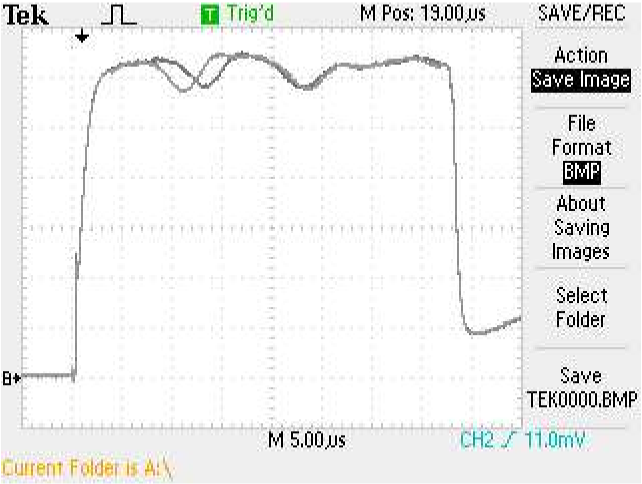

Action
Save Image
File Format
BMP
Current Folder is A:\

Figure 12.5.2 Captured Screen image showing the two reference waveforms.

Save the waveforms

Press the **SAVE/RECALL** button and select the **Save image** option using the on-screen button.

Insert a **USB memory stick** into the oscilloscope **USB socket**.

Press the (on-screen) **Save** button to store the image as a bit-map (.bmp) file.

13. METHOD FOR TESTING A ROTOR AT SPEED

13.1 CAUTION - SAFETY CONCERNS

Any testing carried out on a rotating rotor must be carried out with extreme care and with the explicit permission and under the supervision of the local plant operator. All local safety rules and procedures must be complied with.

13.2 WHY TEST AT SPEED ?

It is well-known that many shorted turns clear when the rotor is at rest and only re-appear at speed. The reason is that these shorts are affected by the centrifugal forces encountered when the rotor is turning at high-speed.

Some of these pressure-dependant shorts may be detected with the rotor at rest by rotating the rotor and taking measurements at various angles until it has been rotated a full turn. In this case, the RSO test will sometimes detect a short at one angle but not at others.

However, for those shorts which clear completely when the rotor is at rest, a spinning RSO test may be necessary.

The most useful information is obtained if the test is conducted either while the rotor is being run up to speed from rest, or while it is run down to rest from synchronous speed. The method is essentially the same as for testing a stationary rotor except of course that it is necessary to make contact with moving slip rings and shaft earth connections.

13.3 PRACTICAL DETAILS FOR TESTING A ROTOR AT SPEED

1. If the brushgear cages can be isolated from the field supply, then connections can be made to the slip rings via the brushgear. However, in most cases it is not possible to isolate the brush cages. An alternative option in a repair works is to use temporary insulated brushgear as shown in figure 13.3.1.

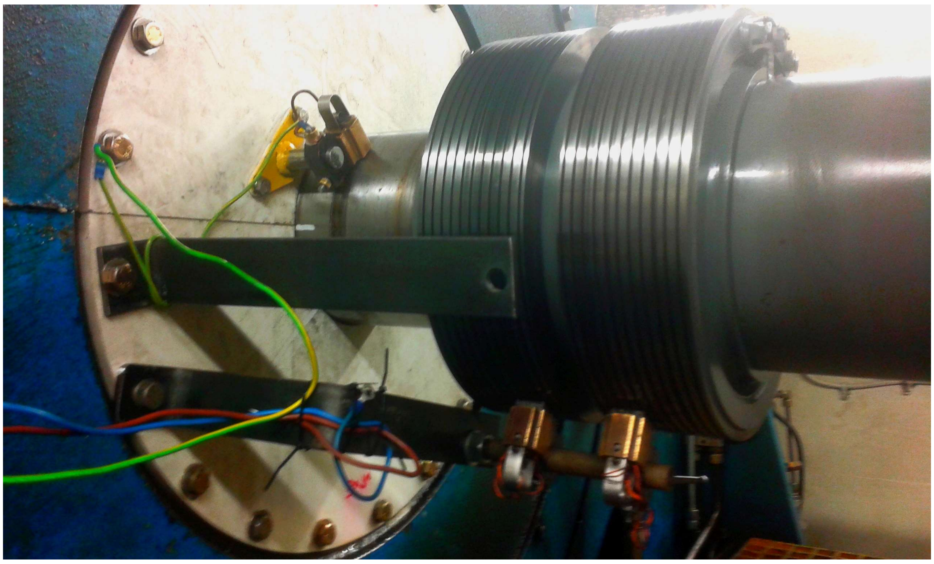


Figure 13.3.1 Running RSO test using temporary test brushes.

2. If the brush cages cannot be isolated, or temporary test brushes as shown in figure 13.3.1 cannot be used, then it is necessary to remove all of the brushes from the cage and install insulated brushes that have been previously prepared. In anticipation of the test, three brushes per slip ring should be removed from the cages and marked so that they can be reinserted in the positions from which they have been removed.

The removed brushes must be machined undersize and insulated as described in section 13.3.1 before being replaced in the brush cages.

3. Experience has shown that it is necessary to use brushes that have been in service in the machine and which have been passing current. This technique does not work if new brushes are used because these give very poor contact with the slipring for the low-voltage RSO pulses. The insulated brushes should therefore be installed in the machine a few days prior to the test.

13.3.1 PREPARING A SET OF INSULATED BRUSHES

This work must be carried out several days before a running RSO test can be carried out.

1. Remove 3 brushes per slip-ring from the in-service generator to be tested, label them 1-6 **and note their locations so that they can be replaced in the same positions in the brush cage**.

2. Replace the missing brushes with new ones and continue to run the generator.

3. Obtain some suitable insulating material (eg Tufnol or epoxy sheet) which can be glued to the sides of the removed brushes.

4. Machine the brushes undersize (to suit the thickness of the insulating material) so that when the insulating material is glued to the sides of the brushes, the insulated brushes are slightly larger than the internal dimensions of the brush holders.

5. Cut the insulating material to size so that when it is assembled to the brush, the arrangement will be as shown in figure 13.3.2.

6. Glue the insulation to the sides of the undersize brush and let the epoxy adhesive set.

13. Fill the top section with epoxy adhesive as shown in figure 13.3.2. and let it set. This is to insulate the brush from the contact spring.

8. Machine the brush insulation so that the dimensions W1 and W2 in figure 13.3.2 allow the insulated brush to be a sliding fit inside the brush holder.

9. A few days before the RSO test, install the insulated brushes in the generator in their previous locations so that they carry current for a short period of time.

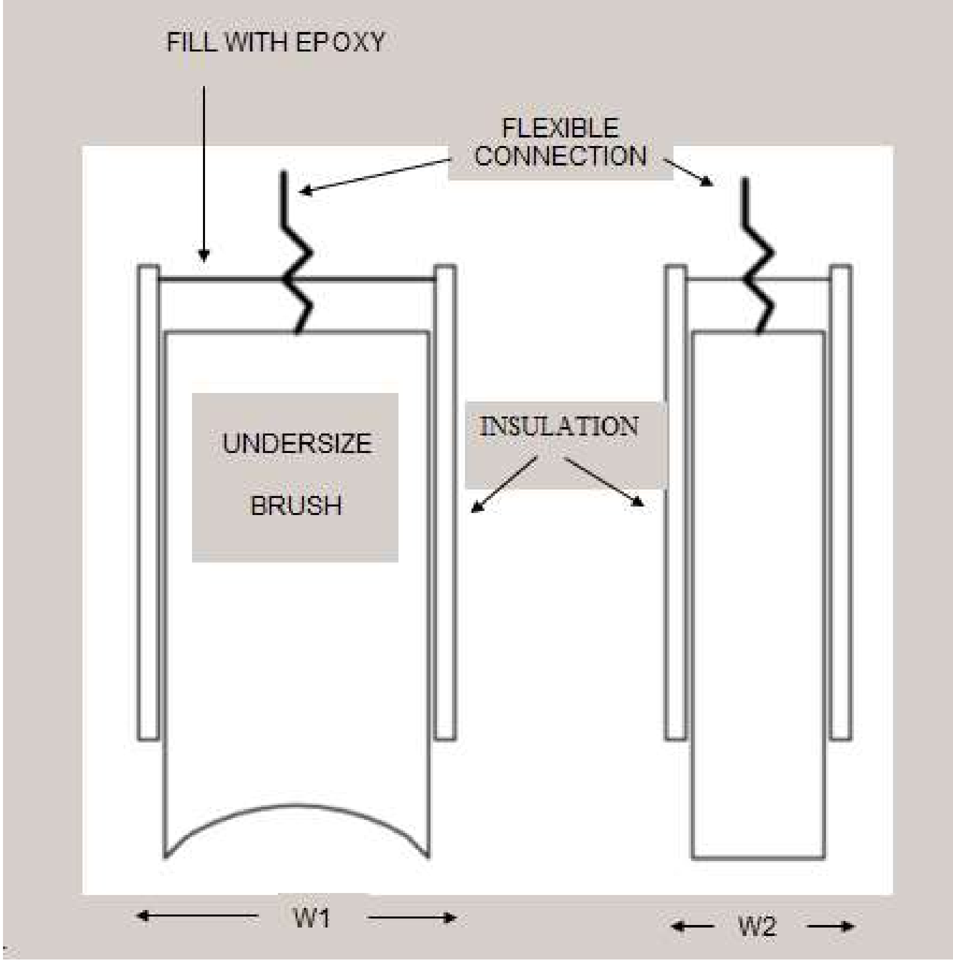


Figure 13.3.2 Side views of insulated brush

13.3.2 THE EARTH CONNECTION BRUSH

It is necessary to make a separate earth connection to the rotor shaft. However, it has been found by experience that it is seldom satisfactory to use an existing shaft earth brush for this test because of the large amount of electrical noise generated by these devices.

The most effective method is make a temporary earth brush and hold it against the a cleaned area of the rotor shaft. One form of temporary earth brush can be made by stripping off the last few centimetres of insulation from a length of stranded heavy-duty earthing cable and taping it to the end of a length of insulated material (eg a wooden broom handle). This temporary earth brush can then be held in contact with the rotating shaft. **

A connection should also be made from this temporary shaft earth brush to a static earth point on the frame of the generator for safety purposes and the green RSO ground test lead should also be connected to this point.

**** But see safety warning in section 13.3.**

13.3.3 TEST DETAILS

A running RSO test is often carried out as a generator is run down from synchronous speed following a period on load. The following test details assume the RSO test is to be carried out on a conventional rotor with slip (collector) rings.

In this case, the rotor excitation system is normally connected directly to the brush cages and cannot easily be disconnected from them. Consequently, before carrying out the RSO test, all of the existing (non-insulated) brushes must be removed from the brush cages and either removed entirely or (in practice), just left dangling by their flexible tails (connecting conductor braids). Ensure that the brushes do not touch the brush cages (using some form of temporary insulation).

At this point, there should be no electrical contact between the slip rings and the brush cages (check this with an electrical test meter).

With the insulated brushes in the brush cages in their original positions (see section 13.3.1), the sets of insulated brush tails in each slip ring cage should be connected together to form 2 sets of tails (one set per slip ring).

Measure the **contact resistance** between the slip rings via the sets of tails of the insulated brushes, which should be less than 1 Ohm. Next measure the insulation resistance between one set of insulated brushes and the rotor shaft, which should **not be less than 100 K Ohms**.

Also measure the **contact resistance** between the temporary earth brush and the rotor shaft which should be less than 1 Ohm.

Connect the brown and blue RSO test leads to the tails of each set of insulated brushes and the green test lead to the rotor earth brush.

Figure 13.3.1 shows the RSO test lead connections for a running RSO test being carried out in a repair shop using a set of temporary test brush gear.

With the modifications mentioned above, the RSO test can be carried out as the rotor speed is increased or decreased by holding the temporary earth brush against the rotor shaft. **However, this operation must be carried out with great care and under approved supervision to avoid any possible harm to the person holding the temporary earth brush.**

The RSO equipment should be set to monitor the waveforms at the **input ends** of the rotor and should be watched carefully for any changes in either trace which may indicate a speed dependent fault. If a fault (or a change in the RSO waveforms) is noted, **the waveforms should be recorded** using the **TDRPlot SAVE button** or by digital photography if in **analogue mode**.

If unusual or unexpected results are obtained, recheck the earth and insulation test lead continuity and also check that the RSO equipment is working correctly by connecting the remote ends of the test leads to the delay line instead of the rotor.

If all is now OK, reconnect the test leads to the rotor and re-check all of the connections at the rotor. Then continue with the test as above.

13.4 MINIMISING THE EFFECTS OF IMPERFECT BRUSH CONTACT

One problem which can occur is that the **test brushes** make poor contact at specific points on the slip ring or rotor shaft, resulting in noisy or erratic RSO waveforms.

It is always best to try to ensure that good brush contact is made. However, it may be possible in some cases to obtain good results even with poor brush contact.

Although for most test conditions, the **TDR200** is intended for use under **PC-control**, this is one situation where **analogue mode** may be useful. The preferred option is to use averaging in **Digital Mode** as described in section 13.4.2 below, but if this is not successful, the following method can be tried using **Analogue mode**.

13.4.1 Operation in analogue mode to overcome brush contact problems

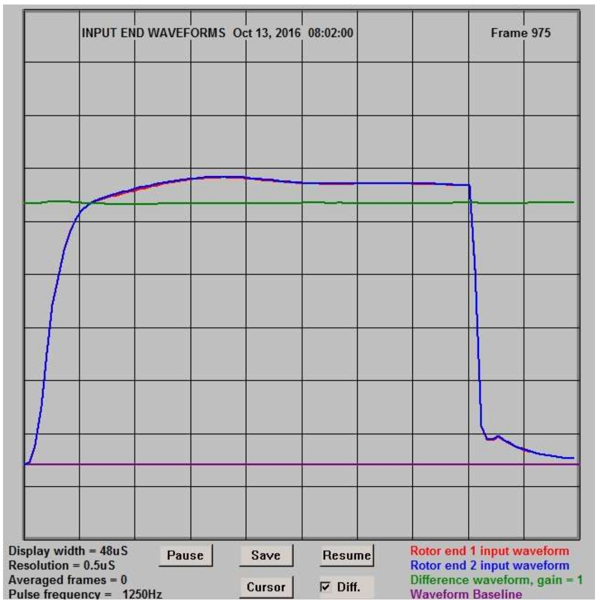
When the **TDR200** unit is operated in **analogue** mode with an **oscilloscope,** it is sometimes possible to adjust the **RSO pulse frequency** so that it is synchronous with the rotation speed of the rotor.

This technique can be used to minimise any trace noise caused by incomplete brush contact, by manually controlling the **RSO pulse frequency** using the front panel **frequency control,** so that the pulses are always injected at the same point on each slipring. This is done by careful adjustment of the **Frequency** control while observing the **RSO traces** on the oscilloscope until the brush noise is minimised.

13.4.2 TESTING A ROTOR AT SPEED IN DIGITAL MODE

The following paragraphs and figures give further information about testing a rotor at speed using the **TDR200** unit in **digital mode** using **averaging.**

13.4.2.1 Test results obtained with rotor at rest.


INPUT END WAVEFORMS Oct 13, 2016 08:02:00

Frame 975

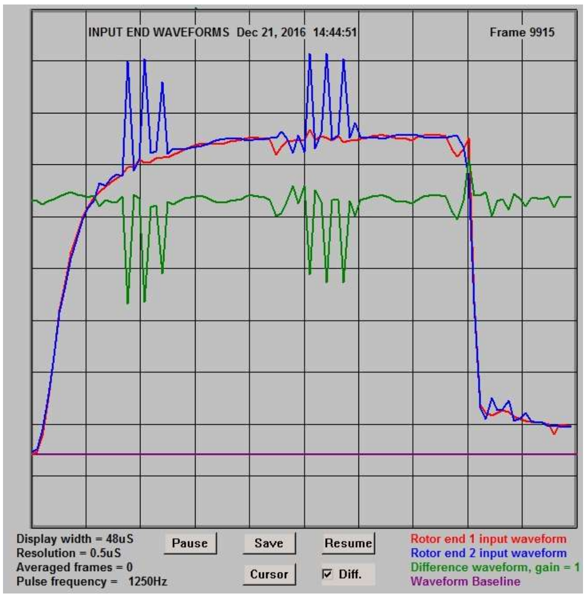
Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

☑ Diff.

Figure 13.4.1 fault-free 500MW rotor at rest.

Figure 13.4.1 shows a set of test results for a fault-free 500MW rotor at rest, while Figure 13.4.2 shows the tests results obtained for the same rotor while rotating at 3000 rpm.

13.4.2.2 Test results obtained with rotor at 3000rpm.



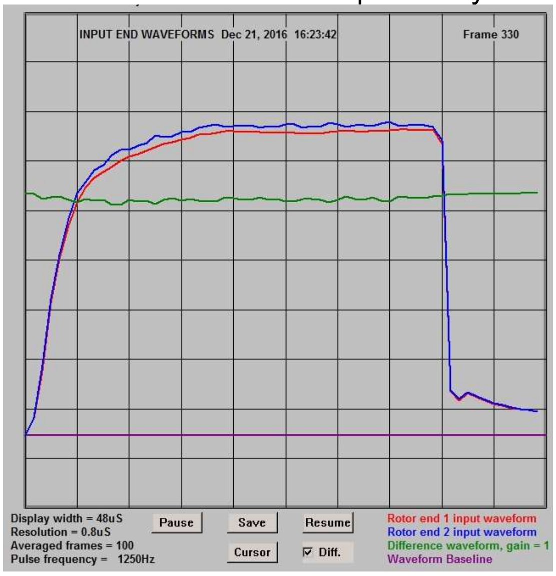
Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 13.4.2 Rotor rotating at 3000 rpm. Poor brush contact

While the brush connected to end 1 of the winding (the red trace) is making reasonably good contact with the slip rings, the brush connected to end 2 (the blue trace) is making very poor contact, producing erratic results in the blue and the green (difference) waveforms.

13.4.3 Improving the results obtained at 3000 rpm using averaging.

The next figure shows how the test results can be improved by the use of rolling averaging.



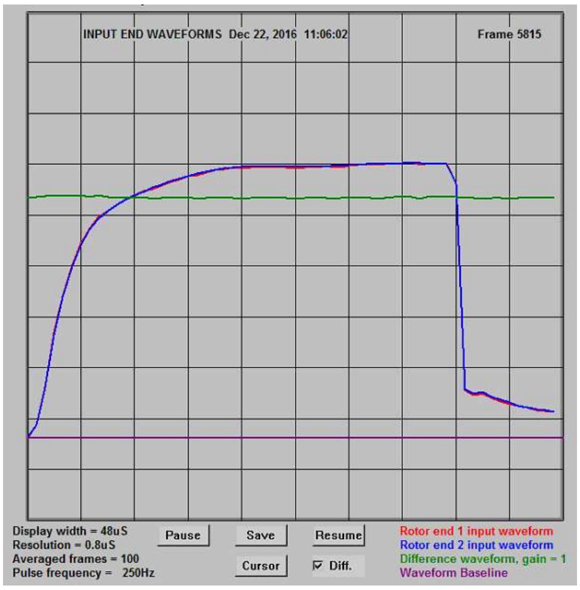
Display width = 48uS
Resolution = 0.8uS
Averaged frames = 100
Pulse frequency = 1250Hz

Figure 13.4.3 Improving the results using averaging.

Figure 13.4.3 was obtained by setting the **Control window** to average **100 frames of data** on a rolling basis. The brush noise on the blue waveform has been almost eliminated and appears instead as a slight vertical displacement of the blue trace, similar to the effects which would be caused by a high-resistance in series with the brush at end 2 of the winding.

13.4.4 Results at 3000 rpm obtained with improved brush contact.

Finally, the results shown in figure 13.4.4 show the RSO waveforms at 3000 rpm after a new set of insulated carbon brushes had been fitted to the rotor. These results confirm that good results can be obtained when carrying out the RSO test at speed, as long as good brush contact is maintained with the rotor slip rings.



Display width = 48uS
Resolution = 0.8uS
Averaged frames = 100
Pulse frequency = 250Hz

Figure 13.4.4 Improved brush contact

14. TESTING LAMINATED ROTORS

14.1 CYLINDRICAL ROTORS

Most rotors of large electrical turbogenerators are fabricated from solid steel cylindrical forgings. However, some smaller rotors (particularly **exciter rotors**) use a laminated construction (similar to that used for stators), One immediate consequence of this is that there is no longitudinal connectivity between the individual circular laminates of the rotor body and so the transmission line analogy is no longer valid.

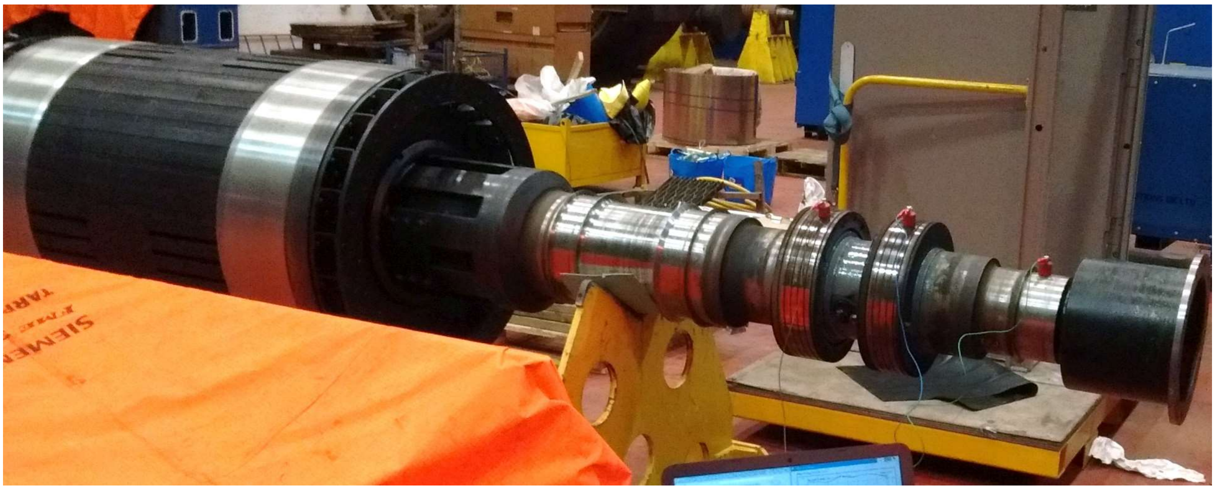


Figure 14.1 RSO test on a laminated exciter rotor removed from stator

Figure 14.2 shows an example of the RSO test waveforms obtained for this rotor

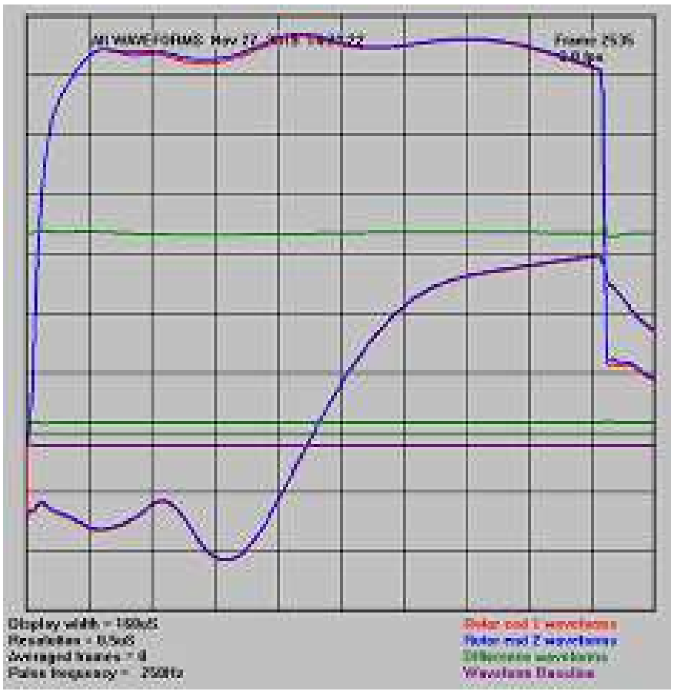


Figure 14.2 RSO test waveforms obtained for a laminated rotor

The upper traces show the RSO waveforms at the input ends of the rotor and the lower traces show the waveforms at the output ends.

These results are not typical of those from a large main rotor in the following respects:

1. The rotor characteristic impedance is very high (> 1000 Ohms).

2. There is evidence of multiple mode propagation.

Looking at the RSO image for the input ends results (upper waveforms), the red trace shows the waveform injected at the slip ring connected to the Red test lead and the Blue trace shows the similar waveform injected at the slip ring connected to the Blue lead. These waveforms are almost identical and there is no evidence of any winding fault. The green waveform is the difference between the red and blue traces.

Looking at the results for the output ends (lower waveforms), the red/blue traces are unusual in that instead of a zero trace region before the pulse arrives at the output ends, there is a large oscillating waveform, which makes it difficult to measure the single-pass transit time accurately. This may be evidence of a second mode of propagation through the winding, possibly due to direct capacitive coupling between the conductors. This sometimes occurs with large rotors but at a much lower level.

To summarise, the RSO test has confirmed that the rotor winding is probably fault-free. However, the results are not typical of those that would be expected from a large forged cylindrical rotor and it would be difficult to locate any winding faults because of the imperfect transmission line properties of this type of rotor.

14.2 SLOW-SPEED SALIENT POLE ROTORS

Figure 14.3 A salient pole rotor

Another type of laminated rotor is used in slow-speed, multi-pole water-powered hydro-generators as shown in figure 10-3. These exhibit similar properties to laminated cylindrical rotors when RSO tests are carried out.

PART 4

This contains sections 15 and 16 which describe how to locate winding faults using the RSO test.

The section contents are as follows:

15. **Locating faults by time scaling**. This section gives detailed information for locating winding faults and the use of the **locate algorithm** in the TDRPlot software.

16. **Locating faults by applying mirror faults**. This section describes a more accurate method for locating winding faults when the rotor has been removed from the generator.

15. LOCATING FAULTS USING TIME SCALING

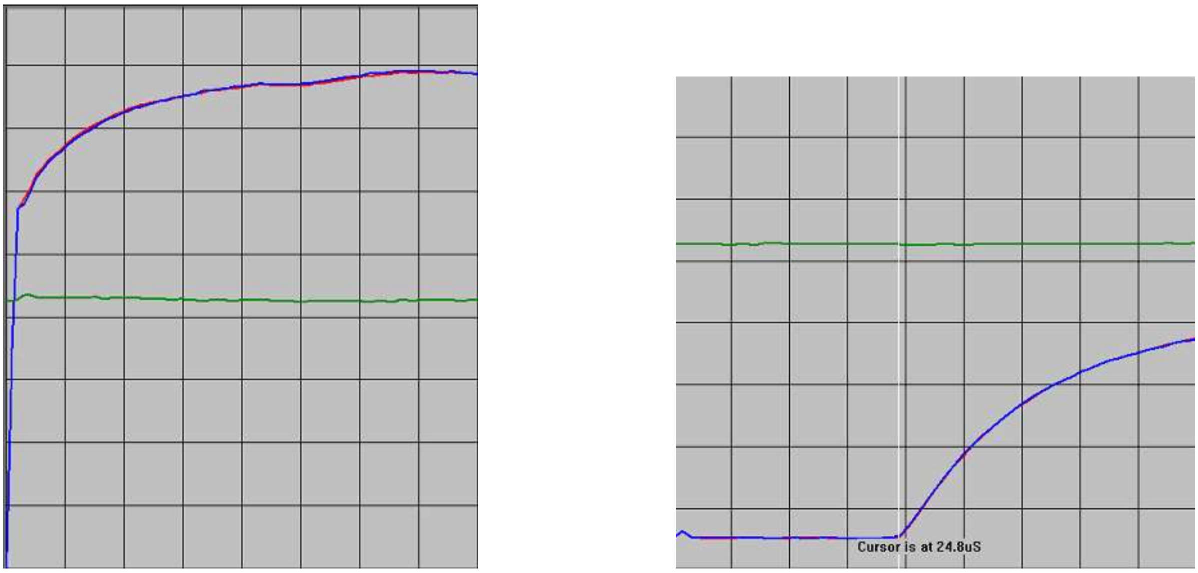
15.1 OVERVIEW

In principle, the location of any **winding fault** can be found by measuring the time to the point of **waveform divergence** and comparing this with the **single-pass transit time** (SPT). This is the time taken for the pulse injected at one end of the rotor winding to travel through the winding to the other end. It is measured easily by viewing the output end waveforms as described in section 2.5.2.

In practice, this only give approximate results for the following reasons:

The rotor winding is an imperfect transmission line, consisting of multiple sections, each having differing characteristic impedances. In particular the impedance in the slot regions is very different from that in the end ring regions. The winding is therefore a periodic structure and the effect on the applied pulse waveform is similar to that of passing it through a low-pass filter.

In addition other (non-transmission line) modes of propagation exist which travel at different speeds from the main mode and these further distort the output pulses. A further problem is that at the fault location, it can be unclear where to measure the point at which the waveforms diverge.



(a) Input end waveforms **(b) Output end waveforms**

Figure 15.1 Pulse distortion.

The pulse applied by the TDR200 via R1 is a true square pulse. However, at the output of the input-matching resistor R1, it has become distorted by the rotor input impedance, as shown in figure 15.1(a) above. By the time it has travelled to the far end of the winding, it has become a pulse with an exponentially increasing leading edge, as shown in figure 15.1(b).

Because of the progressive distortion of the pulse as it travels along the rotor winding, the effective pulse transit time through the rotor winding is non-linear. This can be confirmed by measuring and comparing both the single-pass (SPT) and the double-pass (DPT) transit times. The DPT is the time taken for the pulse to travel through the winding and back again to the input end. It is measured by monitoring the input end waveforms and adjusting the value of the output end matching resistor to cause a deliberate impedance mismatch, as described in section 2.6.2. The Double - pass transit time is normally longer than 2 x the Single - pass transit time, indicating that the effective pulse speed of propagation slows down as the pulse travels further along the rotor winding.

The effect of this is that the pulse appears to travel further per unit time near the start of the winding and less far as it reaches the far ends of the winding.

15.2 TRANSIT TIME CALCULATION

One method for dealing with the non-linear transit time problem was proposed by G.A. Elsworth of the UK Central Electricity Generating Board (CEGB). The basis of the method is to approximate the relationship between the transit time **t** and the distance travelled through the winding **d** as a second-order polynomial of the form:

$$\mathbf{t = A.d + B.d^2} \qquad \mathbf{(1)}$$

where **A** and **B** are constants for a specific rotor winding.

The values of t and d can be measured for 2 specific conditions (the single and dual-pass transit times SPT and DPT), giving 2 simultaneous equations which can be solved to obtain the values of A and B as follows:

$$\mathbf{SPT = A.d1 + B.d1^2} \qquad \mathbf{(2)}$$

$$\mathbf{DPT = A.d2 + B.d2^2} \qquad \mathbf{(3)}$$

where d1 is the length of the rotor winding (d) and d2 = 2.d1 = 2.d

So the equations become:

$$\mathbf{SPT = A.d + B.d^2} \qquad \mathbf{(4)}$$

$$\mathbf{DPT = 2.Ad + 4.B.d^2} \qquad \mathbf{(5)}$$

Solving for A and B we obtain:

$$\mathbf{A = (4.SPT - DPT) / (2.d)} \qquad \mathbf{(6)}$$

$$\mathbf{B = (DPT - 2.SPT) / (2.d^2)} \qquad \mathbf{(7)}$$

Re-arranging equation (1)

$$\mathbf{B.d^2 + A.d - t = 0} \qquad \mathbf{(8)}$$

which is a quadratic equation with solution:

$$\mathbf{df = - A \ +/- \ SQRT(A^2 - 4.B.tf) / (2.B)} \qquad \mathbf{(9)}$$

So for any measured time to the fault **tf**, we can use equations 6, 7 and 9 to obtain the distance **df** of the fault from one end of the winding. In practice, the positive solution of equation 9 gives the correct value of df.

15.3 SOFTWARE IMPLEMENTATION

The equations derived in section 15.2 have been incorporated into the **TDRPlot** software and are implemented using the **Locate** button in the **Control** window.

Before the **Locate** button can be used, the following measurements must be carried out and the results noted:

1. Delay period before start of input pulse
2. Rotor single-pass transit time (measured using output ends plot window).
3. Rotor double-pass transit time (measured using input ends plot window).
4. Time to fault (trace divergence) (measured using input ends plot window)
5. Number of winding end nearest fault.
6. No of rotor coils per half-pole winding.

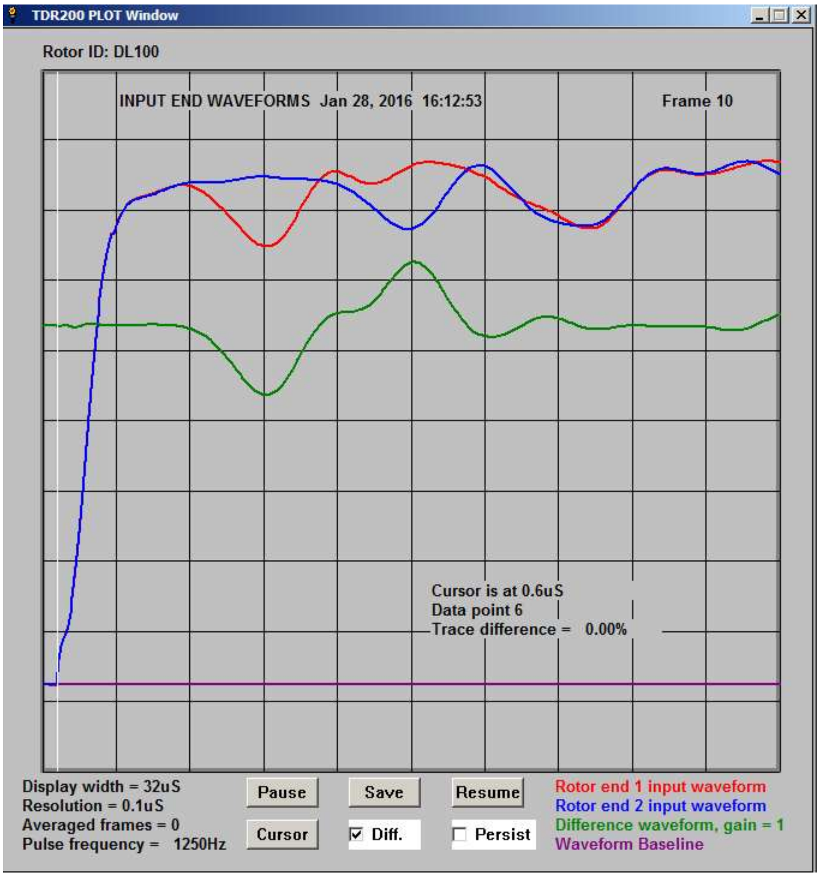
The methods used to measure these quantities are described in the next section.

15. 4 MEASUREMENT OF INPUT PARAMETERS FOR THE LOCATE PROGRAM

15.4.1. Delay period before start of input pulse

This parameter is obtained from the **input ends** plot window.

There is a short **time delay** in the electronic switching circuitry before the **start of the input pulse** appears in the **plot window**. This time (the **input pulse start delay time**) can be measured using the **input ends** plot window as shown below.



TDR200 PLOT Window

Rotor ID: DL100

INPUT END WAVEFORMS Jan 28, 2016 16:12:53

Frame 10

Cursor is at 0.6uS
Data point 6
Trace difference = 0.00%

Display width = 32uS
Resolution = 0.1uS
Averaged frames = 0
Pulse frequency = 1250Hz

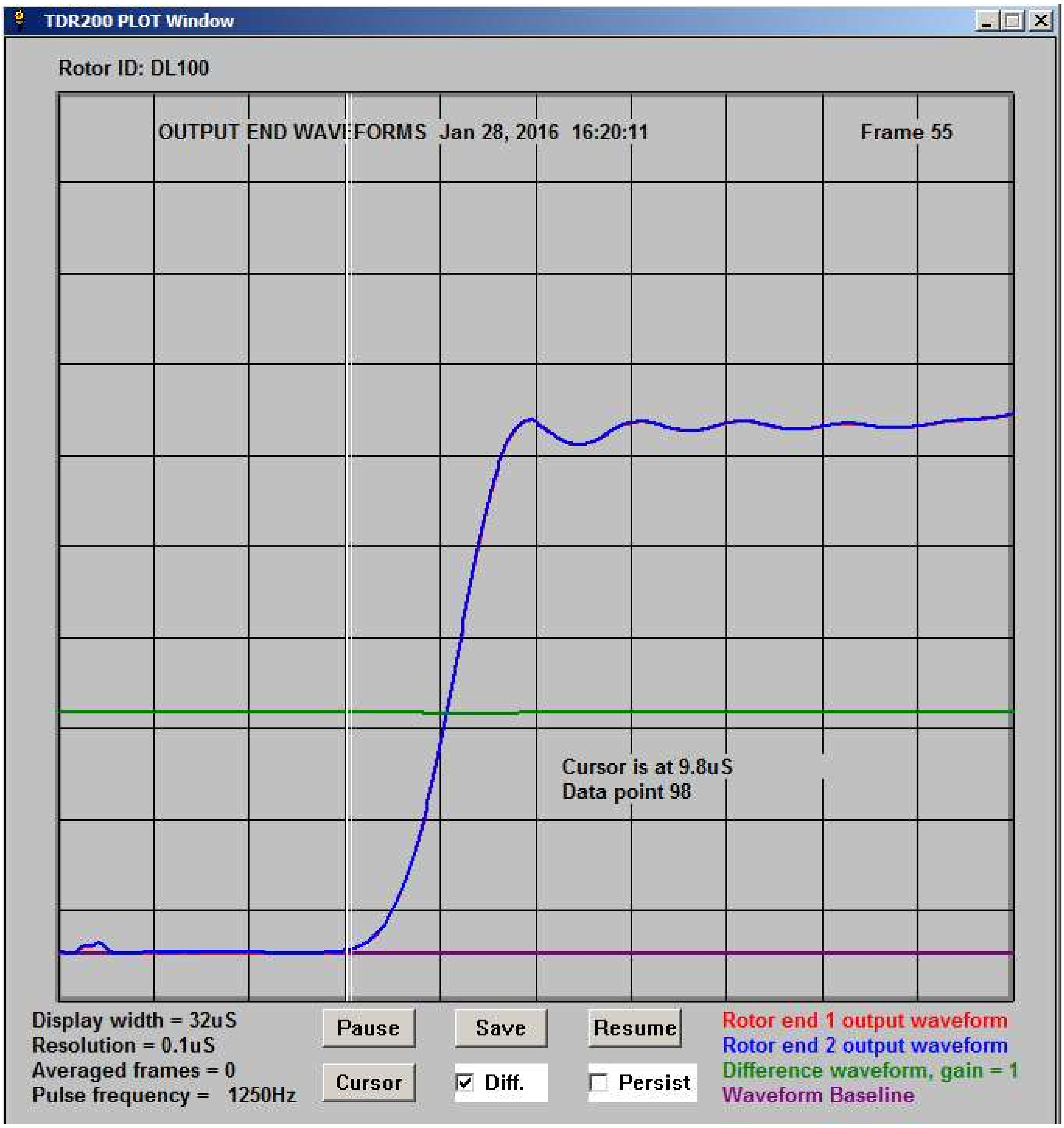
☑ Diff.
☐ Persist

Figure 15.4.1 Measurement of input pulse start delay (0.6uS)

Locate the cursor at the point at which the input pulse waveform starts to increase from zero, as shown above and note this time, which is the **input pulse start delay time** (**0.6 uS** in this case).

15.4.2. Rotor single-pass transit time

This parameter is measured using the **output ends** plot window as shown in figure 15.4.2 below.



TDR200 PLOT Window

Rotor ID: DL100

OUTPUT END WAVEFORMS Jan 28, 2016 16:20:11

Frame 55

Cursor is at 9.8uS
Data point 98

Display width = 32uS
Resolution = 0.1uS
Averaged frames = 0
Pulse frequency = 1250Hz

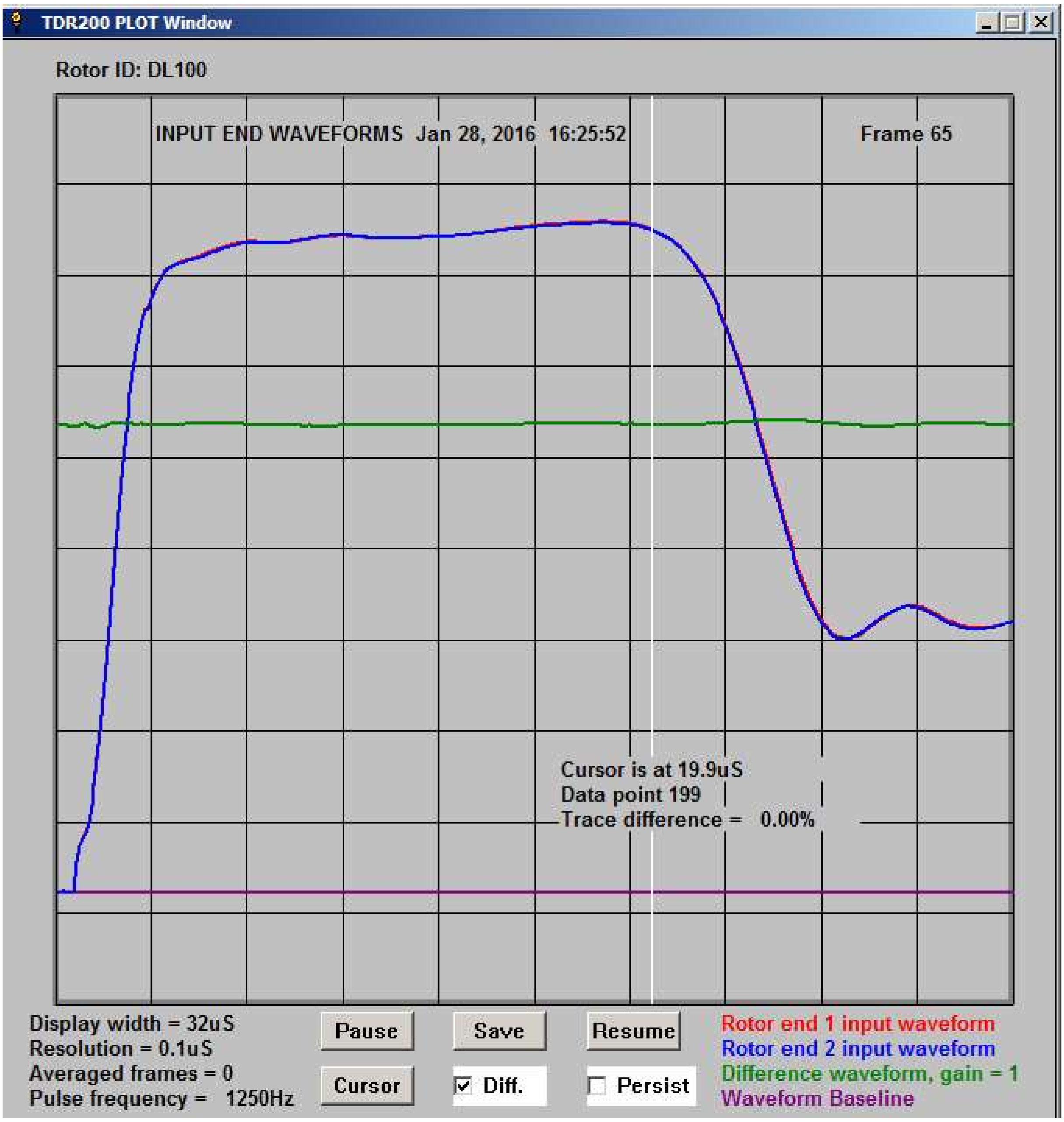
☑ Diff.
☐ Persist

Figure 15.4.2 Measurement of single-pass transit time (9.8uS)

Simply locate the cursor at the point where the output waveform starts to increase from zero and record the **single-pass transit time** (**9.8uS** in this case)**.**

15.4.3 Rotor double-pass transit time

This parameter is measured using the **input ends** plot window by deliberately setting the value of the impedance matching resistor R2 to zero. This cause a negative-going reflection as shown below.



Rotor ID: DL100

Cursor is at 19.9uS
Data point 199
Trace difference = 0.00%

Display width = 32uS
Resolution = 0.1uS
Averaged frames = 0
Pulse frequency = 1250Hz

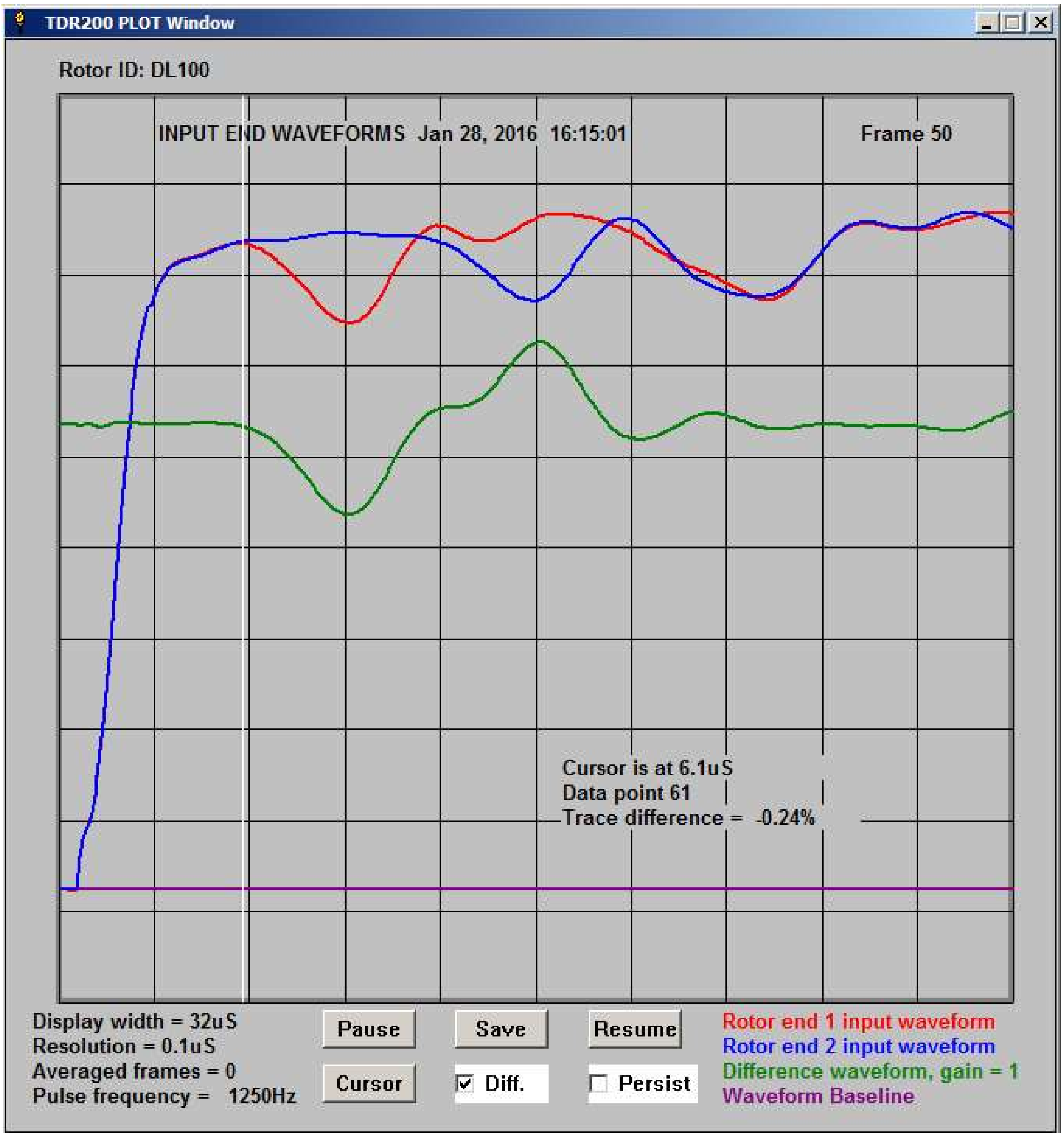
Figure 15.4.3 Measurement of double-pass transit time (19.9uS)

This is the most difficult parameter to measure accurately because of the nature of the waveforms reflected from the far ends of the rotor winding. It should be measured at the point where the waveforms have just started to decrease as shown above **(19.9uS** in this case)..

15.4.4 Time to fault (trace divergence)

This parameter is obtained from the **input ends** plot window.

Figure 15.4.4 below shows the waveforms obtained using the demonstration delay line with a short circuit applied between coil (4-5).



Rotor ID: DL100

INPUT END WAVEFORMS Jan 28, 2016 16:15:01

Frame 50

Cursor is at 6.1uS
Data point 61
Trace difference = -0.24%

Display width = 32uS
Resolution = 0.1uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 15.4.4 Measurement of time to fault (6.1uS)

The time to the fault is measured by locating the cursor at the point at which the red and blue waveforms start to diverge, as shown above (**6.1uS** in this case).

This concludes the set of measurements required to locate the winding fault.

However, it is also necessary to note which winding end is closest to the fault and to note the number of coil slot-pairs in each half-winding.

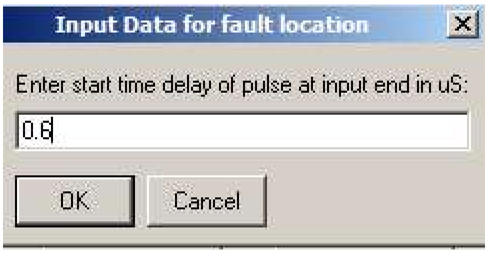
15.5 CALCULATING THE FAULT LOCATION.

Once the measurements have been completed, the **Locate** button in the **Control window** can be used to calculate the approximate fault location as follows:

Click on the **Locate button** in the **Control window**. A series of **prompt windows** will appear and text messages will be generated in the message window.

Input the data requested for each prompt window and then press **Return** to move onto the next window. If using a mouse, try to keep its position still, as this affects the location of the **prompt windows** on the PC screen.

Note that default values appear in some of the windows. Simply over-write these values with the correct ones.



Enter start time delay of pulse at input end in uS:

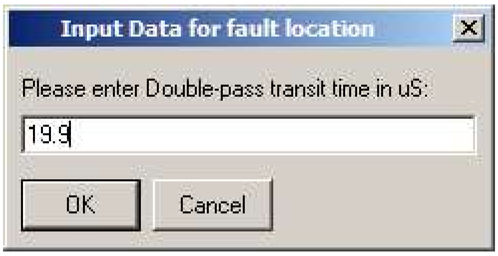
0.6

Figure 15.5.1 Prompt window for Start delay time

Please enter Single-pass transit time in uS:

9.8

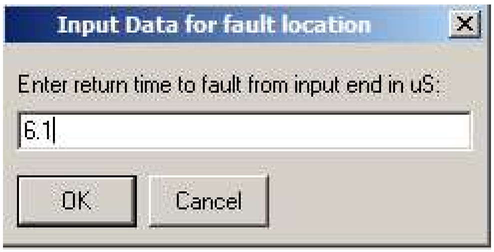
Figure 15.5.2 Prompt window for single-pass transit time



Please enter Double-pass transit time in uS:

19.9

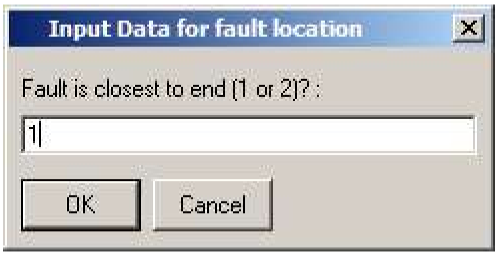
Figure 15.5.3 Prompt window for double-pass transit time



Enter return time to fault from input end in uS:

6.1

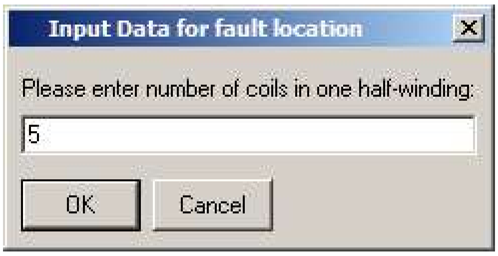
Figure 15.5.4 Prompt window for time to winding fault



Fault is closest to end (1 or 2)? :

1

Figure 15.5.5 Prompt window for input end number



Please enter number of coils in one half-winding:

5

Figure 15.5.6 Prompt window for number of coils in each half-winding

This completes the input data and the location results are printed in the message window. A typical output example follows:

```
Number of rotor coils in each half-pole winding is 8
Corrected single-pass transit time is 9uS
Corrected double-pass transit time is 21uS
Corrected double-pass time to fault is 7uS
Corrected single-pass time to fault from End 1 is 3.5uS

Distance to fault from End 1 is approximately 43% of winding length
Fault is probably in coil 7 from RED end 1
```

Figure 15.5.6. Example of output in Message window

16. FAULT LOCATION BY APPLYING MIRROR FAULTS.

16.1 OVERVIEW

The time scaling method can only give the approximate fault location. The fault can be located more accurately by carrying out a series of further tests if the rotor has been removed from the generator.

The basic idea is to apply an identical temporary fault to the **fault-free half winding** as described below. By adjusting the position of this fault until the waveforms for the 2 winding ends are identical or nearly so, the faulty turn can usually be identified.

If the rotor has radial cooling holes, it may be possible to access the winding turns using a special shorting probe. The practical details are discussed below.

Otherwise, similar techniques can be used once an end ring has been removed. However, If one or both end rings are removed, the shapes of the RSO waveforms may differ considerably from those for a rotor with the end rings in-situ, as shown in figure 11.9.1. Moreover, because the windings can expand radially in the absence of the end ring, two slightly different traces may be obtained for a rotor that is known to be fault-free, because the expansion of the end region windings may not be uniform.

It should be noted that removing the end rings **increases the characteristic impedance of the rotor in the end-winding regions and also the overall mean characteristic impedance of the rotor winding.**

16.2 PRACTICAL DETAILS FOR MIRROR FAULT METHOD

If a winding fault has been detected in the rotor, and the end rings have been removed, it is possible to find the approximate location of the fault by putting a similar fault onto the other half winding of the rotor and moving the position of this deliberate fault until two identical traces are obtained. This can be done by using insulated probes.

16.2.1 LOCATING EARTH FAULTS

If an earth fault is suspected, then one of the probes should be earthed to the rotor body using a short flexible lead, and the end winding should be probed until the application of this fault causes similar traces to appear. The faulted coil can be found by touching the probe onto the outer turn of each coil in the end region of the winding. When the coil which causes the traces to almost coincide has been located, the faulted turn can be located by moving the probe radially down this coil in the end winding region and making contact with the sides of the conductors (which are not usually insulated). When the turn has been located which causes the traces to coincide (or nearly so) its coil number and turn number (found by counting turns down from the outside of the winding) should be noted. The fault lies in the equivalent coil in the other half winding.

It is possible to use this same technique without removing the end rings if the rotor contains radial cooling holes that run next to the conductor slots. In this case, the winding can be probed directly.

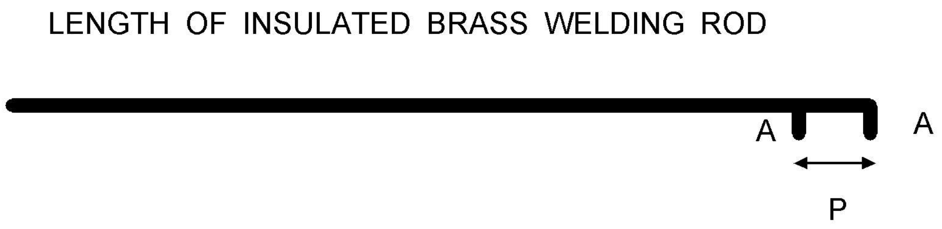
16.2.2. LOCATING INTER-TURN FAULTS

The position of an inter-turn fault can be located using two probes connected via a length of insulated flexible lead. In this case, adjacent turns of the opposite half-winding are shorted together to locate the fault.

The length of the lead connecting the insulated probes should be kept to a minimum to improve the measurement sensitivity.

An alternative improved method is to make up a special two-pronged probe to apply the shorts between adjacent turns.

An example of this type of probe is shown below.



A short lengths of welding rod brazed to main section

P = pitch between adjacent turns of rotor winding

Figure 16.3 Probe for locating shorted turns

This type of probe minimises the impedance of the applied short and gives better measurement sensitivity,

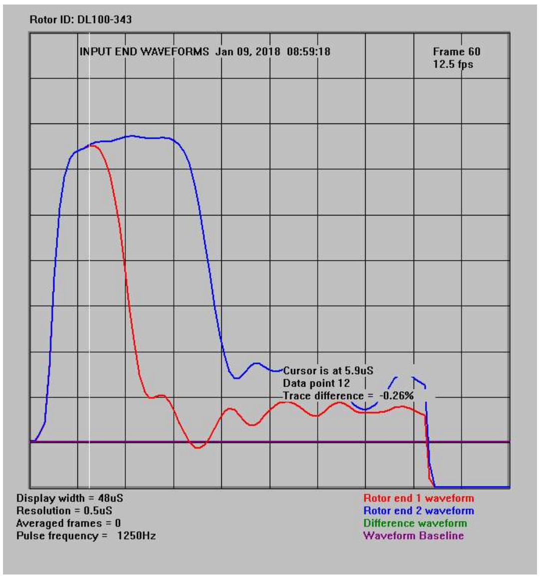
16.3 ESTIMATING THE SINGLE-PASS TRANSIT TIME FROM RSO WAVEFORMS FOR A ROTOR WINDING CONTAINING AN EARTH FAULT

If a rotor winding contains an **earth fault**, it is not possible to measure the **single-pass transit time** directly, as the waveforms viewed at the **output ends** of the winding will be zero traces. It is, however possible to estimate this time by analysing the waveforms reflected from the earth fault at the input ends of the winding to obtain the **double-pass transit time**.

An **earth fault** will cause the amplitude of the pulse monitored at the **input ends** of the winding to start to decrease in amplitude, after the time taken for the pulse to reach the earth fault and be reflected back to the input ends of the winding.

The waveforms shown in figures 16.5.1 and 16.5.2 were obtained using the **Rowtest DL100 demonstration delay line** with a deliberate earth fault applied between terminal 4 and ground. The difference waveforms have been turned off in the figures for clarity. The figures display the input end waveforms reflected from the earth fault. and it is clear that the fault is nearest to the **Red** end (1) of the winding.

In figure 16.3.1, the cursor has been located at the point of divergence between the **Red** and **Blue** waveforms and this shows that for the **Red** waveform, the reflected signal from the fault occurs **5.9uS** after the start of the RSO pulse injected at end 1.

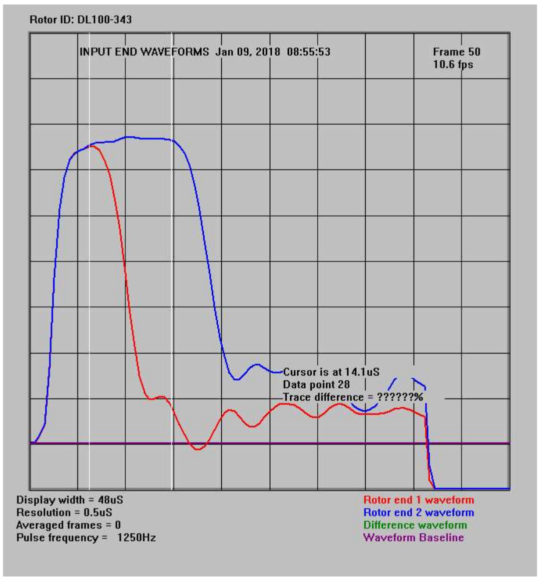


Rotor ID: DL100-343

Cursor is at 5.9uS
Data point 12
Trace difference = -0.26%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 16.3.1 Delay line waveforms with Earth fault applied between terminal 4 and ground



Rotor ID: DL100-343

Cursor is at 14.1uS
Data point 28
Trace difference = ??????%

Display width = 48uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 16.3.2 Delay line waveforms with Earth fault applied between terminal 4 and ground

In figure 16.3.2, the cursor has been moved to the point at which the **Blue** waveform starts to decrease in amplitude. This occurs **14.1uS** after the start of the RSO pulse injected at the **Blue** end (2) of the winding .

By summing these 2 values, the **double-pass transit time** will be 5.9 + 14.1 = 20uS. The **single-pass transit time** will therefore be approximately half this value, ie **10uS**.

PART 5

This contains **3 Appendices** describing software installation, a test result template and some results obtained using a physical model of a rotor winding.

The section contents are as follows:

Appendix 1 Software installation and initialisation (new pc only)

Appendix 2 RSO test report blank Word template

Appendix 3 RSO test results from a rotor model

APPENDIX 1

SOFTWARE INSTALLATION AND INITIALISATION (New PC only)

A1.1 SOFTWARE INSTALLATION

The **TDR200** instruments are supplied with a custom **Control Laptop PC** with pre-installed software. No further software installation is required other than posted upgrades.

A1.2 INSTALLATION INSTRUCTIONS

1. If this software is to be **installed as an upgrade**, first rename your existing **TDRPlot** folder to the new name **TDRPlot-old** to avoid losing any existing data files etc.

2. Copy the folder named **TDRPlot** from the **software CD or USB memory Stick** to the **C\: folder** on the PC.

4. Open the **TDRPlot** folder and then open the **Program files** sub-folder.

5. Make a shortcut to the **TDRPlot.exe** file and move this shortcut to the **PC Desktop**.

6. Close the **TDRPlot** folder.

7. Make a shortcut to the **TDRPlot** folder.

8. Change the 2 **new shortcut icons** to the default versions. These can be found in the C:\TDRPlot\Program files\icons folder.

A1.3 FTD DRIVERS

Install the FTD serial port drivers as follows:

Open the **C:\TDRPlot\Program files\FTD\Virtual Com Port** folder.

Run the **CDM20814_Setup.exe** file.

This will install the required driver files.

A1.4 COM PORT NUMBER

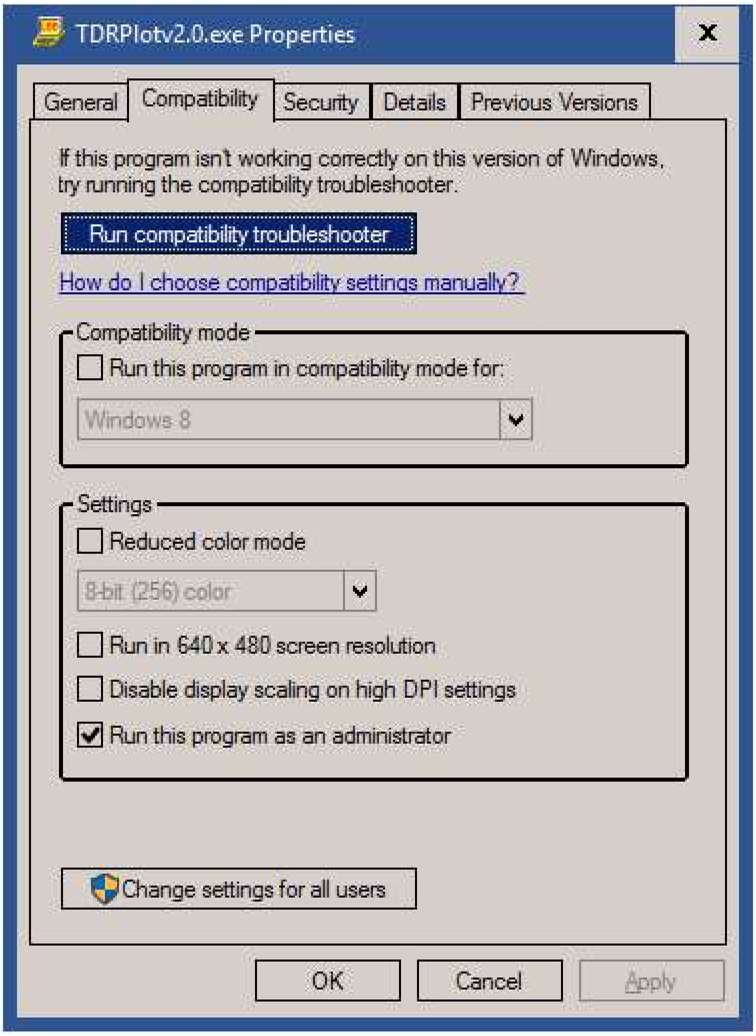
Carry out the instructions listed in **section A1.8** to establish the number of the communications port in use on the **Control PC**.

A1.5. PROGRAM COMPATIBILITY SETTINGS

The programs **TDRPlot.exe** and **Usercode.exe** must be set to "**Run as administrator**" mode. For each program above, this is done as follows:

Right click on the required .exe file in the **Programs sub-folder** and click on the **Properties** option.

When a new window appears, click on the **Compatibility** tab



If this program isn't working correctly on this version of Windows, try running the compatibility troubleshooter.

Compatibility mode

☐ Run this program in compatibility mode for:

Windows 8

Settings

☐ Reduced color mode

8-bit (256) color

☐ Run in 640 x 480 screen resolution

☐ Disable display scaling on high DPI settings

☑ Run this program as an administrator

Click on the "**Run this program as an administrator**" option in the **Settings** box.

Click **OK** to exit the window.

The **TDRPlot software** can now be run by double-clicking on the **TDRPlot shortcut icon**. However, it will be necessary to obtain an **Unlock code** as described in **section A1.7** before the software can be used for each new PC.

A1.6 SETTING UP WINDOWS 11

The following modifications have been made to the **Windows setup** on the Laptop PC supplied with the **TDR200** system:

1. Install the Classic Shell program

The Classic Shell program which displays a conventional Windows Desktop when the PC starts up can be installed by running the **Setup** file in the **Classic Shell sub-folder** within the **TDRPlot Program files** folder.

2. Set the Classic screen Theme.

A close approximation to the **Classic Windows** theme, which gives a high-contrast-type display, can be implemented by copying the file **classic.theme** (located in the **Classic Shell** sub-folder) to the **C:\Windows\Resources\Ease of Access Themes** folder. Then right click on the **Desktop window** > **Personalise** and select the **Classic Theme** option.

Note that this theme may not work correctly for all programs (eg Libre Office). In this case, users can easily switch back to a standard **Windows 11 theme** by right-clicking on the **Windows Desktop,** selecting the **Personalise** option and then selecting another Theme.

3 Set Default applications for file types

This allows files to be opened with a specific program by double-clicking on the file name.

Start button > Control Panel >Default Programs >

Associate a file type or protocol with a program

Now click on the required file extension type and select the program you want to use to open the file.

4. The following additional programs have been installed

Libre Office (for editing text files)

Irfanview (for viewing image files)

Foxit Reader (for viewing pdf files)

5. User account settings.

The following changes need to be made in the User Account Settings section of the Control panel to allow the **TDRPlot** program to run without generating a security query:

Control Panel > User Accounts > Change user account control settings >

Now set the vertical slider to the **Never notify** setting.

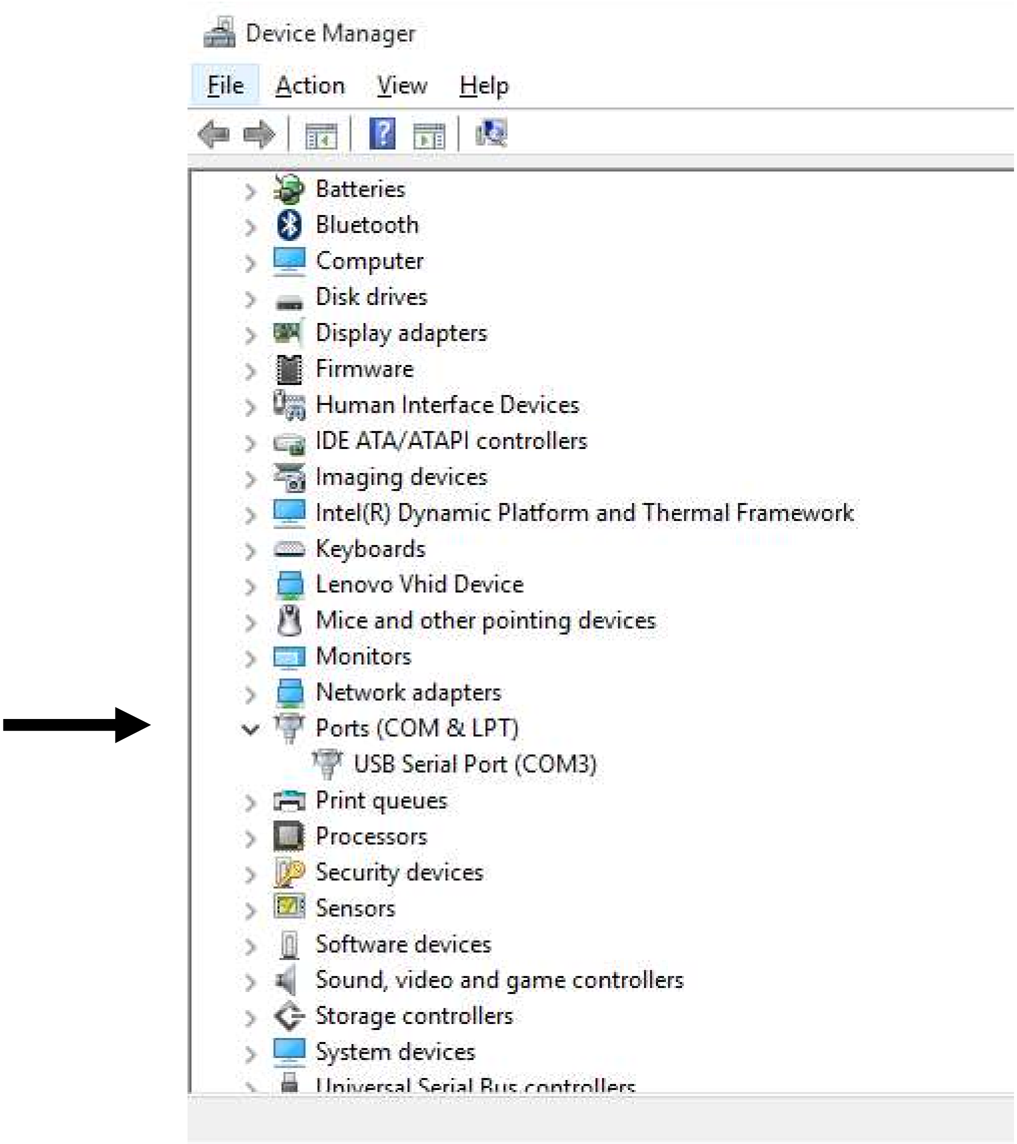
If this change is not made, the PC will always ask permission before running the **TDRPlot program**.

The **TDRPlot** program should now run correctly.

A1.8 FINDING THE PC COMPORT NUMBER (WINDOWS 10/11)

Connect the **Reflectometer** to the **PC** via the **USB cable** and switch it on.

Open the **Control Panel** and select **Device Manager**. The following window is then displayed.



Expand the **Ports (COM & LPT)** option by clicking on the > arrow. The list of com ports in use is displayed.

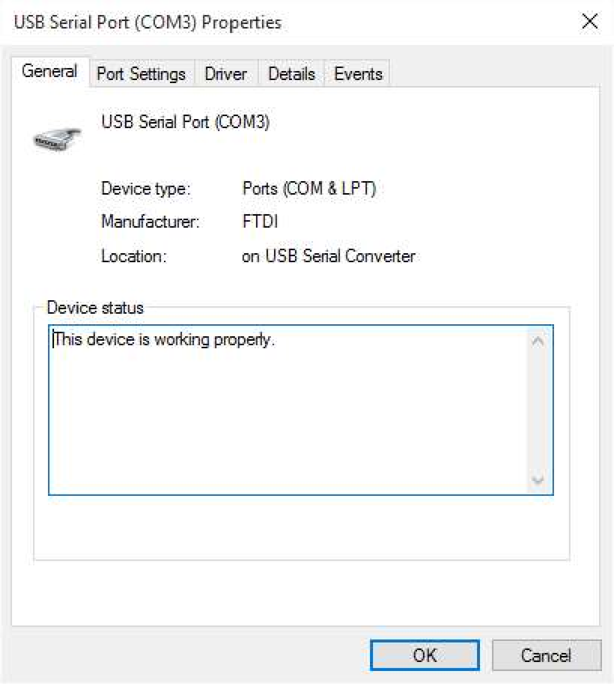
If only one port is shown, (as in the case above) this is the comport number in current use (**COM3**).

This number should be entered in the **comport parameter box** in the **TDRPlot Control window.**

A1.9 CHANGING THE COMPORT NUMBER

If necessary, it is possible to change the allocated **COM port number** as follows:

In the **Device Manager** window (see above) right-click the **USB Serial Port** and select **Properties.**

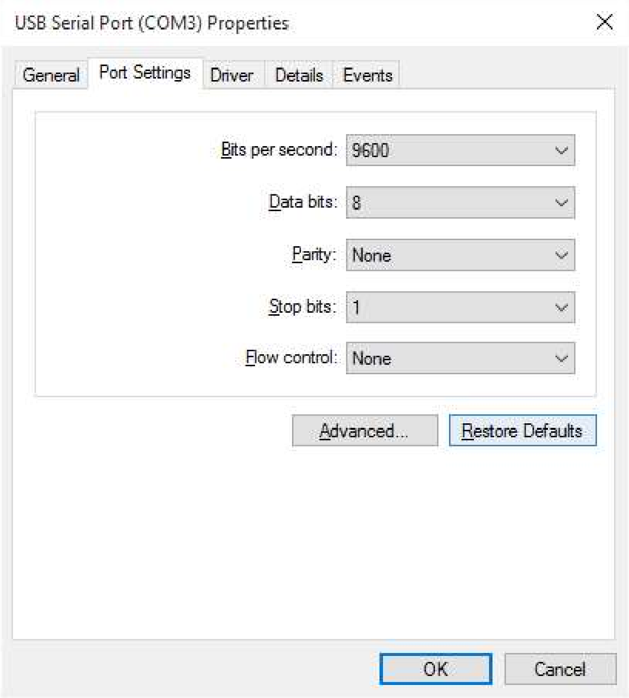


USB Serial Port (COM3)

Device type: Ports (COM & LPT)
Manufacturer: FTDI
Location: on USB Serial Converter

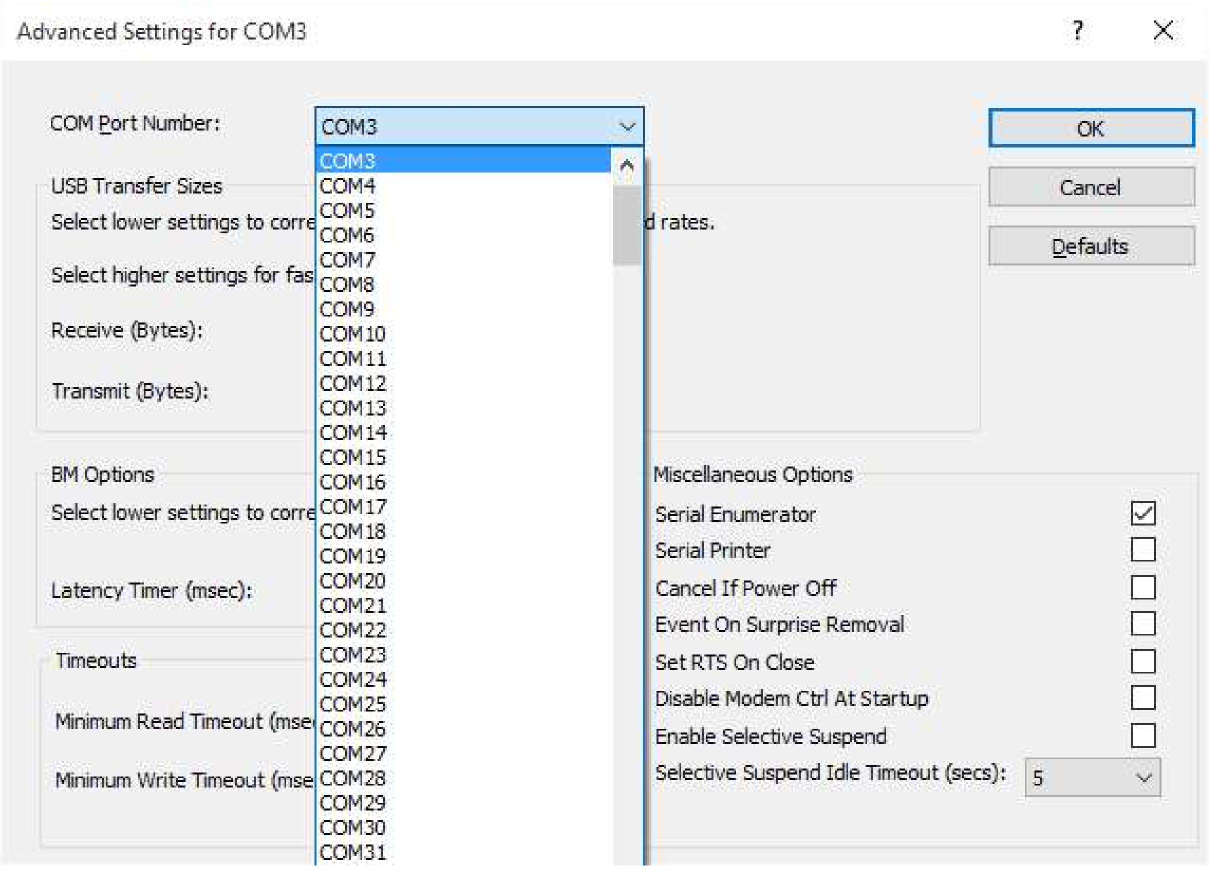
Device status: This device is working properly.

Then select the **Port Settings** Tab.



Bits per second: 9600
Data bits: 8
Parity: None
Stop bits: 1
Flow control: None

Now click on the **Advanced** button and click on the drop-down menu arrow next to the **COM Port Number** box. The list of available COM Port numbers appears



COM Port Number: COM3

Serial Enumerator ☑
Serial Printer ☐
Cancel If Power Off ☐
Event On Surprise Removal ☐
Set RTS On Close ☐
Disable Modem Ctrl At Startup ☐
Enable Selective Suspend ☐
Selective Suspend Idle Timeout (secs): 5

.

Select the required port number and clock OK.

Important Note: Do not change any of the other parameters in this window.

APPENDIX 2 RSO TEST REPORT BLANK TEMPLATE

ROTOR WINDING RSO TEST REPORT

LOCATION: **TEST DATE**:

ROTOR TYPE: **RATING MW**:

MANUFACTURER: **DATE OF MANUFACTURE**:

NUMBER OF POLES:

(a) Input end waveforms **(b) Output end waveforms**

EXCITATION METHOD: SLIP RINGS? ROTATING RECTIFIER?

TEST CONDITIONS
IN STATOR AT REST AT SPEED REMOVED FROM STATOR

END RINGS: IN SITU REMOVED

MEASURED WINDING RESISTANCE:
MEASURED INSULATION RESISTANCE:

SINGLE-PASS TRANSIT TIME (FROM OUTPUT END WAVEFORMS) T1 uS:
DOUBLE-PASS TRANSIT TIME (FROM INPUT END WAVEFORMS) T2 uS:

COMMENTS ON TEST RESULTS

APPENDIX 3

RSO TEST RESULTS FROM A ROTOR MODEL

A3.1. OVERVIEW

It is difficult to carry out a detailed range of RSO tests on a real rotor and so we have attempted to build an electrical model of a typical rotor winding using the techniques used in the demonstration DL100 delay line. This **rotor model** is slightly more complex than the simple version used in the DL100 unit as it attempts to simulate the **losses** which occur in a real rotor winding.

The rotor model is shown in figure 1.1 below.

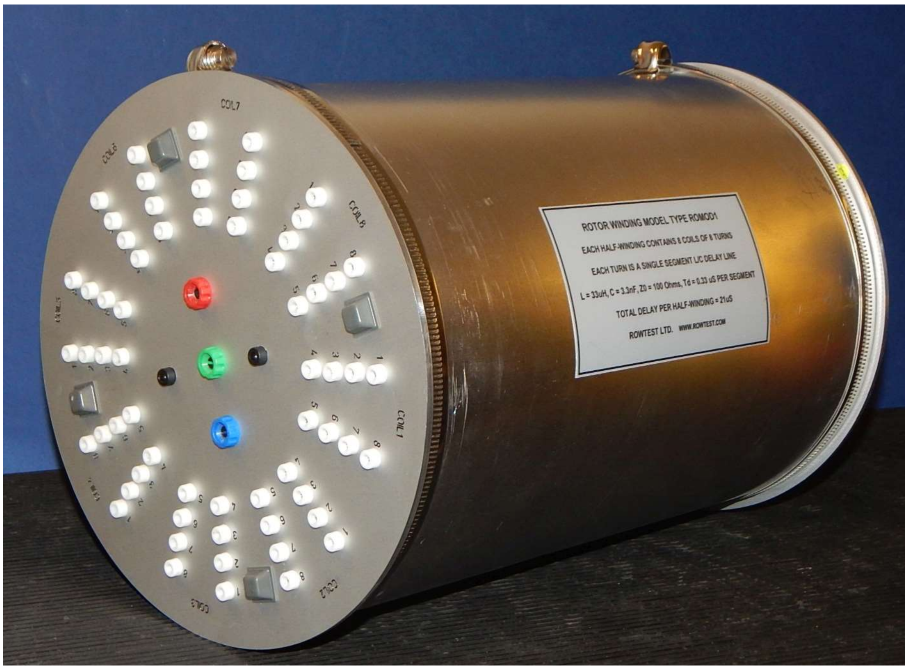


Figure 1.1 Electrical Rotor Model

The model consists of 2 half-windings, each of which contains 8 "coils" having 8 "turns" per coil. The above photo shows one half-winding end of the model . The other end is similar and contains the other half-winding.

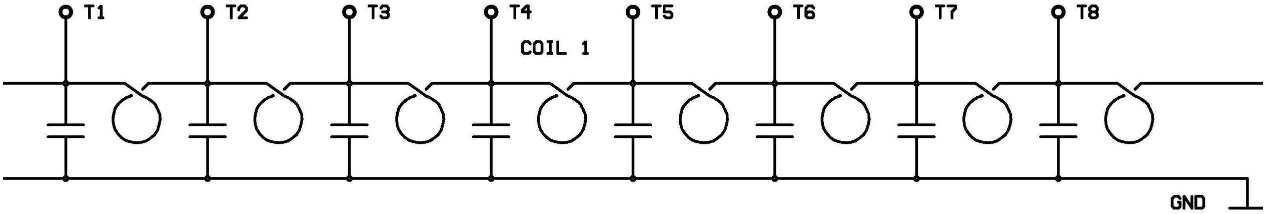


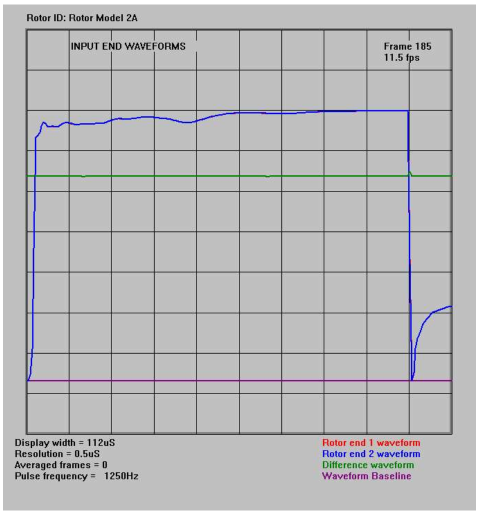
Figure 1.2 Schematic of one coil of 8 turns in model Rotor winding

The model simulates 8 x 8 x 2 = 128 turns in the full winding and the white terminals (T1 - T8 in the above figure) are connected to the junctions between each "turn". This arrangement allows interturn faults to be applied between any pair of turns in the simulated rotor winding.

A3.2. RSO RESULTS FOR FULL WINDING WITH NO APPLIED FAULTS

The results shown in sections 2.1 to 2.4 were measured to confirm that the rotor model functioned as expected for a fault-free rotor winding.

A3.2.1 FAULT-FREE RSO WAVEFORMS



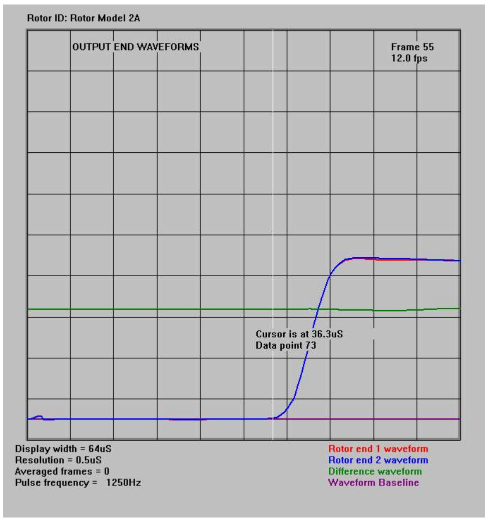
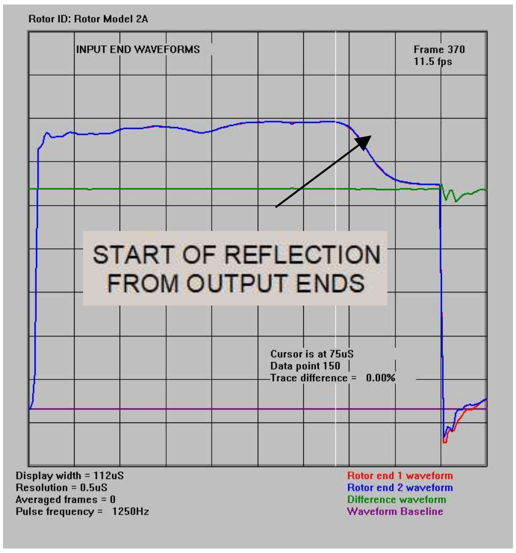


Figure 2.1 Input end waveforms R2 matched. No winding fault.

Figure 2.2 Output end waveforms Transit time is 36uS approx

Note that there are 2 identical waveforms displayed for the fault-free case

A3.2.2 INPUT END WAVEFORMS WITH NO APPLIED FAULTS SHOWING PULSE REFLECTION FROM LOW AND HIGH-IMPEDANCE-TERMINATED OUTPUT ENDS



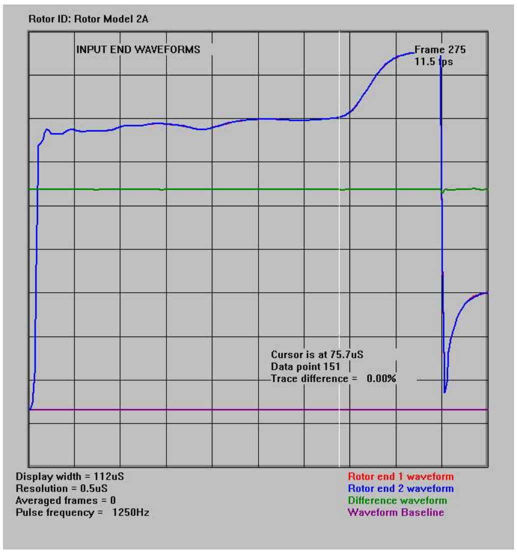


Figure 2.3 Input end waveforms. R2 < Z0. DP transit time around 75uS

Figure 2.4 Input end waveforms. R2 > Z0. DP transit time around 75uS

A3.3 RESULTS FOR FULL WINDING WITH FAULTS APPLIED AT END 1

The results shown in this section were obtained by shorting the first pair of "turns" in each "coil" in one half-winding with R2 set to the matched value Z0 = 100 Ohms.

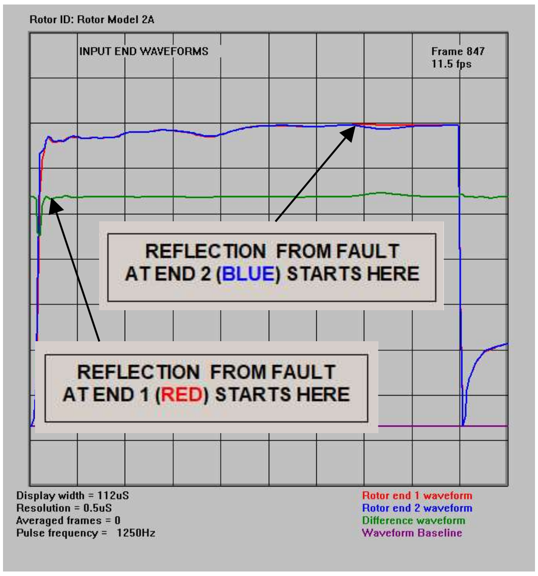


Figure 3.1. Input end waveforms with short between turns 1 and 2 of Coil 1

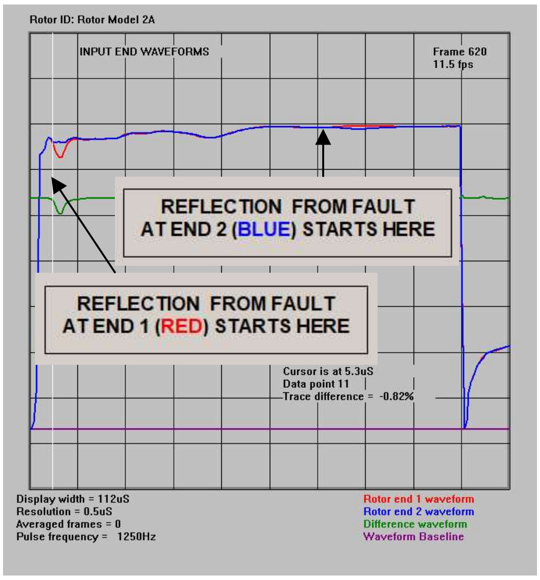


Figure 3.2. Input end waveforms with Short between turns 1 and 2 of Coil 2

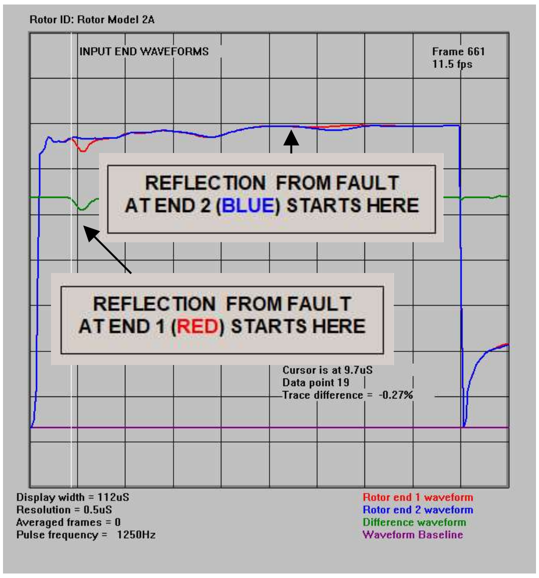


Figure 3.3. Input end waveforms Short between turns 1 and 2 of Coil 3

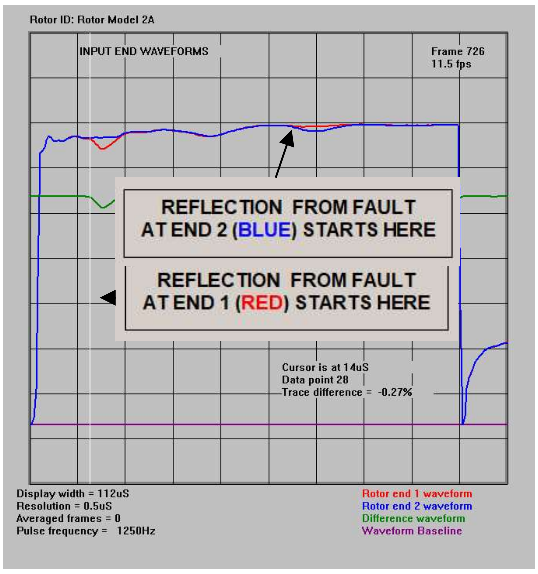
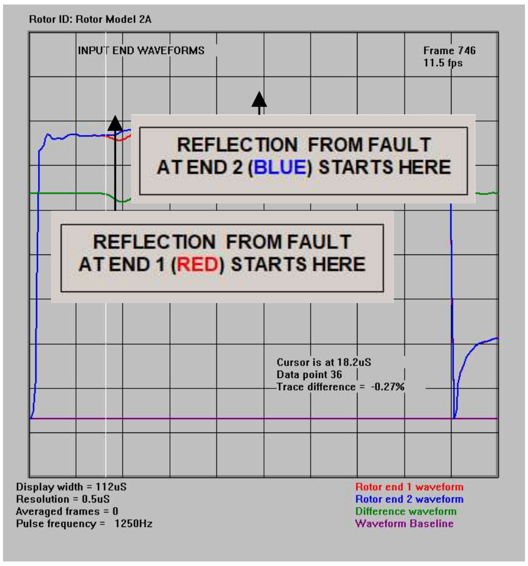


Figure 3.4. Input end waveforms. Short between turns 1 and 2 of Coil 4



Rotor ID: Rotor Model 2A

Frame 746
11.5 fps

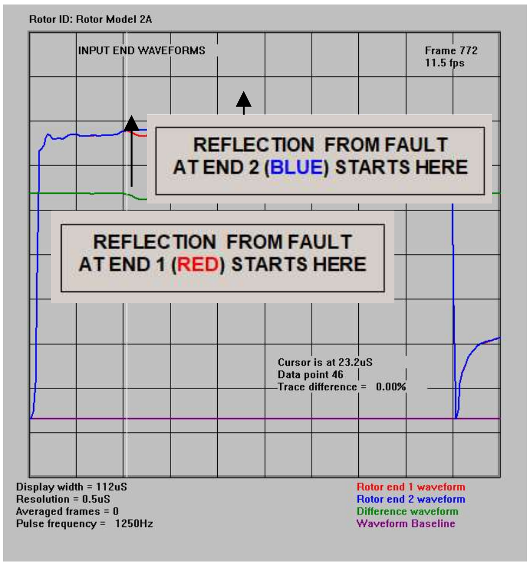
REFLECTION FROM FAULT AT END 2 (BLUE) STARTS HERE

REFLECTION FROM FAULT AT END 1 (RED) STARTS HERE

Cursor is at 18.2uS
Data point 36
Trace difference = -0.27%

Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 3.5. Input end waveforms.
Short between turns 1 and 2 of Coil 5



Rotor ID: Rotor Model 2A

Frame 772
11.5 fps

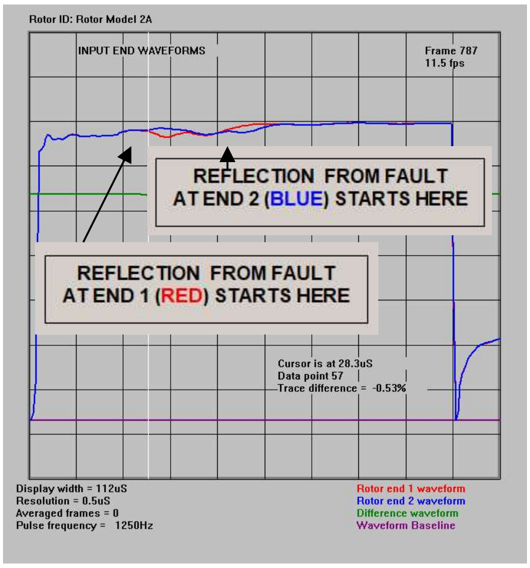
REFLECTION FROM FAULT AT END 2 (BLUE) STARTS HERE

REFLECTION FROM FAULT AT END 1 (RED) STARTS HERE

Cursor is at 23.2uS
Data point 46
Trace difference = 0.00%

Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 3.6. Input end waveforms.
Short between turns 1 and 2 of Coil 6



Rotor ID: Rotor Model 2A

Frame 787
11.5 fps

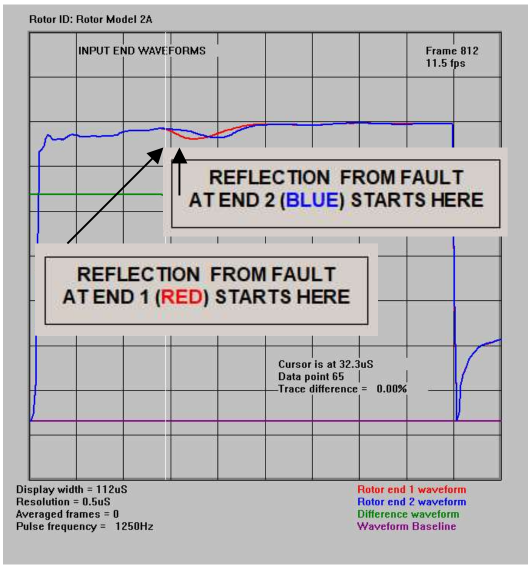
REFLECTION FROM FAULT AT END 2 (BLUE) STARTS HERE

REFLECTION FROM FAULT AT END 1 (RED) STARTS HERE

Cursor is at 28.3uS
Data point 57
Trace difference = -0.53%

Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 3.7. Input end waveforms.
Short between turns 1 and 2 of Coil 7



Rotor ID: Rotor Model 2A

Frame 812
11.5 fps

REFLECTION FROM FAULT AT END 2 (BLUE) STARTS HERE

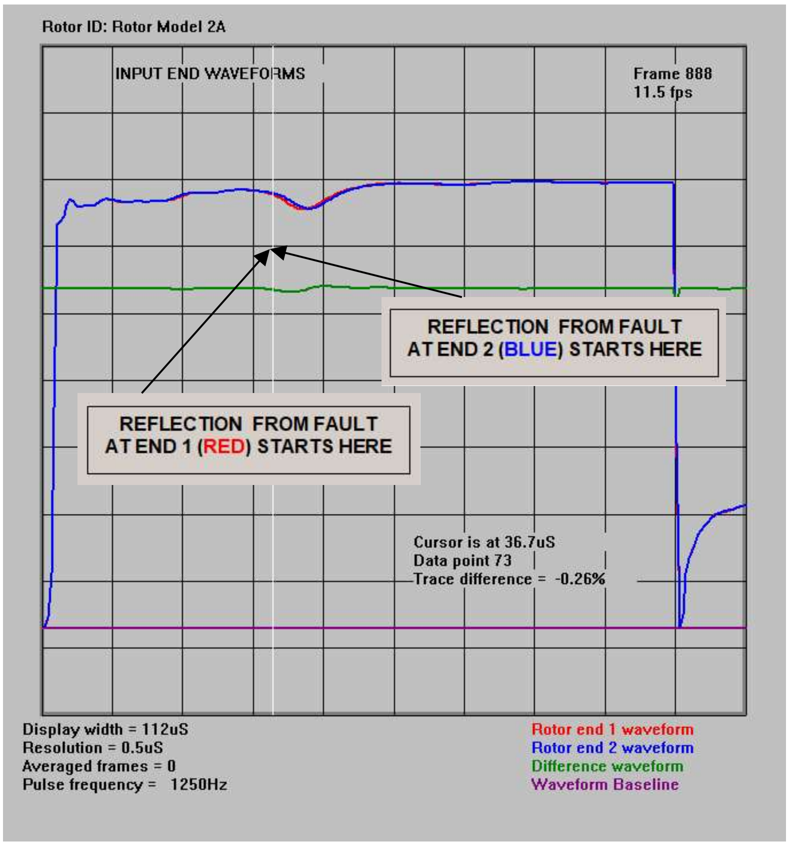
REFLECTION FROM FAULT AT END 1 (RED) STARTS HERE

Cursor is at 32.3uS
Data point 65
Trace difference = 0.00%

Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 3.8. Input end waveforms.
Short between turns 1 and 2 of Coil 8

Note that in figure 3.8, the reflection from end2 (blue) has started to merge with that from end1 (red).



REFLECTION FROM FAULT AT END 2 (BLUE) STARTS HERE

REFLECTION FROM FAULT AT END 1 (RED) STARTS HERE

Cursor is at 36.7uS
Data point 73
Trace difference = -0.26%

Display width = 112uS
Resolution = 0.5uS
Averaged frames = 0
Pulse frequency = 1250Hz

Figure 3.9. Input end waveforms. Short between turns 7 and 8 of Coil 8

Note that the shorted turns are (almost) at the centre of the winding and so the RSO waveforms are almost coincident.

A3.4 MEASUREMENT OF DOUBLE PASS TRANSIT TIMES TO FAULTS

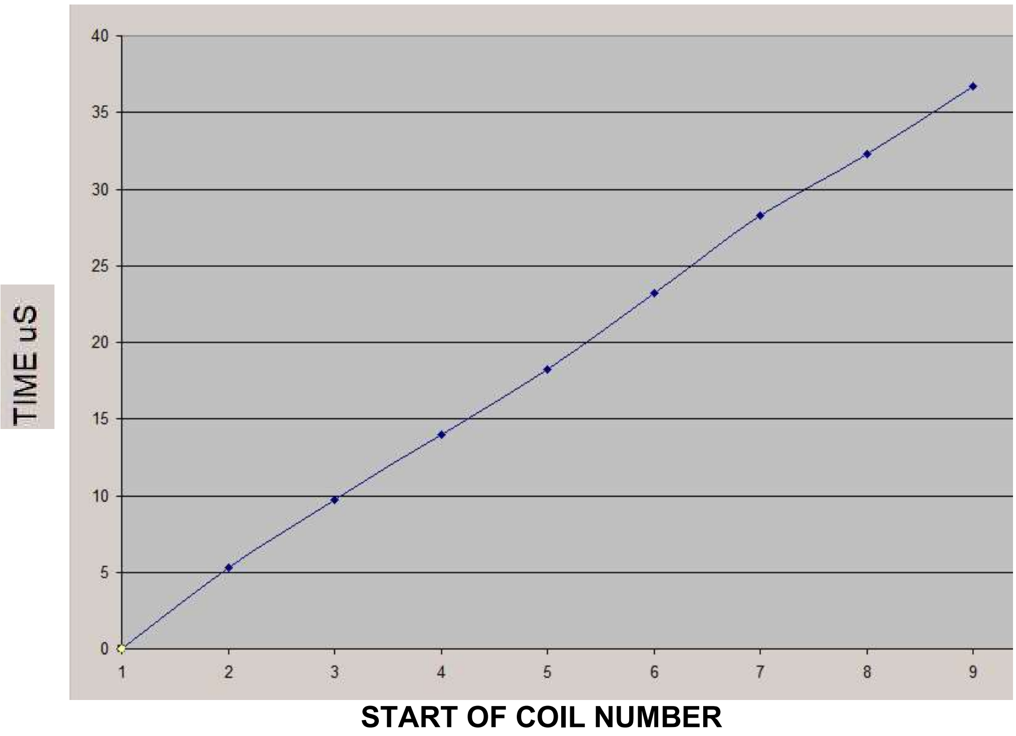


Figure 4.1 Transit time plotted against start of each coil number

(Data derived from figures 3.1 to 3.9)