M4110 Leakage Reactance Interface User Guide

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Preface

Structure of this Manual

This manual consists of 4 chapters and two appendixes.

Chapter 1	"Introduction To Leakage Reactance Testing" introduces the M4110 Leakage Reactance Interface.
Chapter 2	"Understanding Leakage Reactance Testing" provides an overview of Leakage Reactance theory.
Chapter 3	"Leakage Reactance Test Procedures" describes procedures for executing Leakage Reactance tests.
Chapter 4	"Interpretation Of Test Results" explains how to analyze test results.
Appendix A	"Voltage Selection" describes how to change the test set input voltage from 115 volts to 220 volts.
Appendix B	"Part Numbers" lists the parts of the M4110 Leakage Reactance Interface.

Conventions Used in this Manual

The following terms and typographical conventions are used in the manual:

Convention	Description
Windows	Refers to the Microsoft Windows operating system, Version 95 or later.
Click	Quickly press and release the left mouse button.
Double-click	Quickly press and release the left mouse button twice without moving the mouse.
Select	Position the cursor on the desired option and click the left mouse button once. Or, highlight the desired option using the arrow keys and press ENTER. Or, press ALT and the underlined letter.
Press	Type a single keyboard key. For example, press ENTER.
FN+(appropriate key)	Press and hold the FN key, and press (appropriate key).
Bold Courier Text	Indicates characters to be typed.

4. Interpretation of Test Results

Appendix A. Voltage Selection

Appendix B. Part Numbers

1. Introduction to Leakage Reactance Testing

M4110 Leakage Reactance Interface

This optional interface contains the circuitry necessary to convert the voltage and current, measured during a Leakage Reactance test on a transformer, into a form that can be measured by the M4100 Instrument. It also contains a variac so that the proper test voltage can be obtained. The Leakage Reactance test cannot be made without either this Interface or the M4130 Leakage Reactance Module, and the accompanying software. It also requires an M4000 Insulation Analyzer.

When using this interface, the standard M4000 safety switch and safety strobe are used. The necessary current and voltage cables are provided for connection to the transformer, along with the necessary software, so that this becomes a self-contained kit for this test. The user is only limited by the size of the variac provided.

Figure 1.1 M4110 Leakage Reactance Interface

Installing the Software

The Leakage Reactance test requires additional software, and is installed in the same directory as the M4000 software. Run the installation program from the Setup command. Once you have picked the directory, the software installs itself with no dialog boxes. You will be able to run the Leakage Reactance test from the M4000 software, or, if available, from the DTA software. Advantages of using the DTA software include:

1. Your test data is stored in the same file with your power factor, exciting current, turns ratio, oil quality and DGA, and other test data.
2. DTA has forms specifically designed for Leakage Reactance tests.
3. You can store your Leakage Reactance test data in the DTA Office database for future reference.
4. You can easily pull up one file with the entire history of Leakage Reactance tests for a given transformer.

For more information on using the Leakage Reactance test with DTA, see the DTA manual.

What You will Need for the Test

Besides the M4110 Leakage Reactance Interface and its cables, you will need:

1. M4100 and its cables, including the M4100 and either the M4200c Controller or a laptop computer with the M4000 and Leakage Reactance software loaded.
2. Heavy jumper cables, needed to short-circuit the secondary for each test. You will be injecting anywhere from a fraction of an ampere to 3 or so amperes on the High Voltage side, so you must take into account the transformer's turns ratio and use jumpers that can withstand the expected current on the Low Voltage side.
3. To match the nameplate impedance, the transformer must be tested on the same tap positions as were used to obtain the nameplate value. This information must be obtained from the nameplate, and the transformer must be set to those tap positions before the test.

NOTE **To switch between 115 volt and 220 volt operation, see Appendix A.**

What follows in this manual is information on the theory involved, and what exactly is being measured, test connections and test procedure, and finally, test results analysis.

2. Understanding Leakage Reactance Testing

Introduction

Winding deformation which leads to an immediate transformer failure may be the result of several overcurrent events. The probability of overcurrent conditions is not very high and, as a result, a transformer can remain in service with partially deformed windings, although the reliability of such a transformer is reduced. Many transformer failures begin with mechanical deformation but eventually occur for electrical reasons. Consequently, determining mechanical deformation should be given very serious consideration. Even small changes in measured parameters should be treated with the utmost respect.

Several methods have been used to detect winding deformation. They are:

- frequency response analysis
- Iow-voltage impulse test
- capacitance measurement
- leakage reactance measurement

Methods one and two have inherently very promising searching capabilities. The relative sophistication of the instruments and the expertise required for these measurements has yet to allow them to become “household tools” at many utilities.

Capacitance measurements are performed as a part of the routine AC-insulation tests and normally include all three phases. Capacitance between the windings, and between each winding and the core/tank, is a function of their geometric relationships, as well as the dielectric constants of the intervening insulation. It is known that capacitance may exhibit minor variations due to temperature changes or serious contamination.

Leakage reactance measurements are performed by short-circuiting the low voltage winding. During that test, the reluctance encountered by the magnetic flux is determined predominantly by the leakage channel (Figure 2.1).

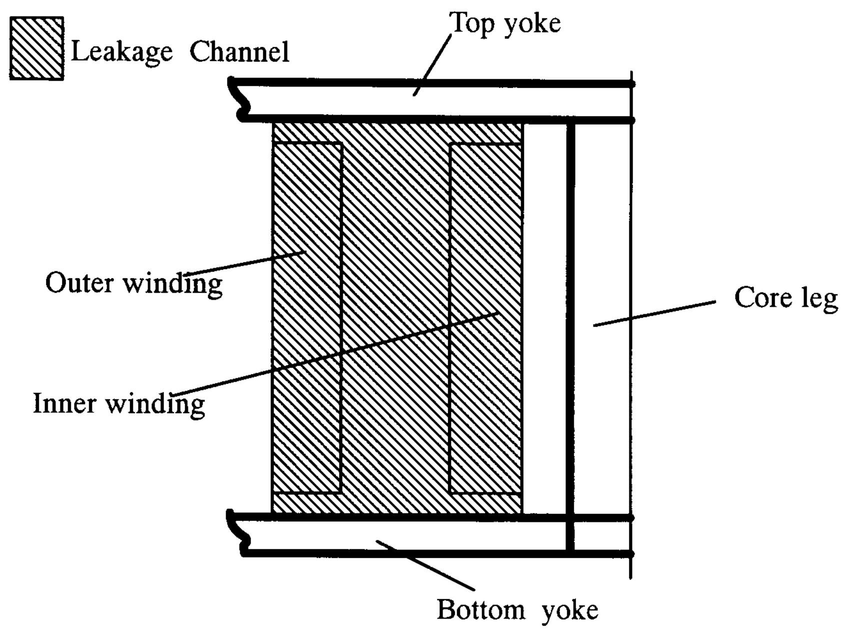


Figure 2.1 Leakage Channel

The leakage channel is the space confined between the inner surface of the inner winding, the outer surface of the outer winding, and the bottom and the top yokes. When winding distortion occurs, it changes the reluctance of the magnetic flux path, resulting in a change of the measured leakage reactance.

The leakage reactance measurement is the simplest of all four tests. During routine transformer test investigations, it is useful to perform both leakage reactance and capacitance tests. The changes in both parameters will serve as a reliable indicator of the winding distortion. Case studies comparing the results of both measurements are presented in *Minutes of the Sixty-First Annual International Conference of Doble Clients, 1994, sec. 6-5.*

It should be noted that the leakage reactance test does not replace the exciting current measurement; the two are complementary. Leakage reactance is influenced by the reluctance in the leakage channel, magnetizing current is influenced by the reluctance in the transformer core and can detect shorted turns in the windings, shorted core laminations, multiple core grounds and problems with the LTC and NLTC.

Failure Modes

When a system short circuit causes high current to flow through a large power transformer, the windings and internal leads are subjected to extremely high mechanical forces. The total radial force on a winding can be multiple millions of pounds and total axial force can be between one and two million pounds. The extremely high current during the fault conditions is a major source of mechanical displacements and subsequent transformer failures.

The current flowing in transformer winding conductors sets up an electromagnetic field in and around the windings, as shown in the simplified sketches of Figure 2.2 and Figure 2.3. Any current-carrying conductor (I) which is linked by this field (B) experiences a mechanical force (F) which is perpendicular to the direction of the current and the field.

In a core form transformer, the forces act radially outward on the outer winding and radially inward on the inner winding, but because of the radial fringing at the ends of the windings, there are also axial force components which tend to compress the windings (Figure 2.2).

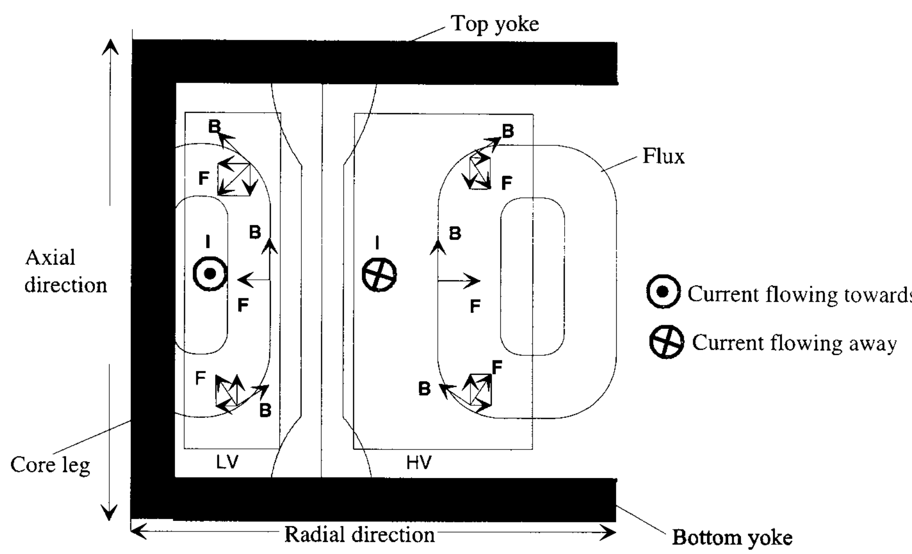


Figure 2.2 Generated Forces in a Core Form Transformer

The common failure modes for a core form transformer are as follows:

- Inward radial hoop buckling
- Outward radial hoop stretching
- Conductor beam bending from generated axial force
- Conductor tilting from cumulative axial force
- Coil end support instability produced by axial force.

Whereas the principal forces in the core form design were radially directed, the principal forces in the shell form are axially directed (Figure 2.3). They tend to separate the low-voltage winding from the high-voltage winding, which pushes the low-voltage winding against the core. The high-voltage wincing is being crushed inward upon itself. There are modest radial force components as well. These tend to compress the pancake winding sections radially.

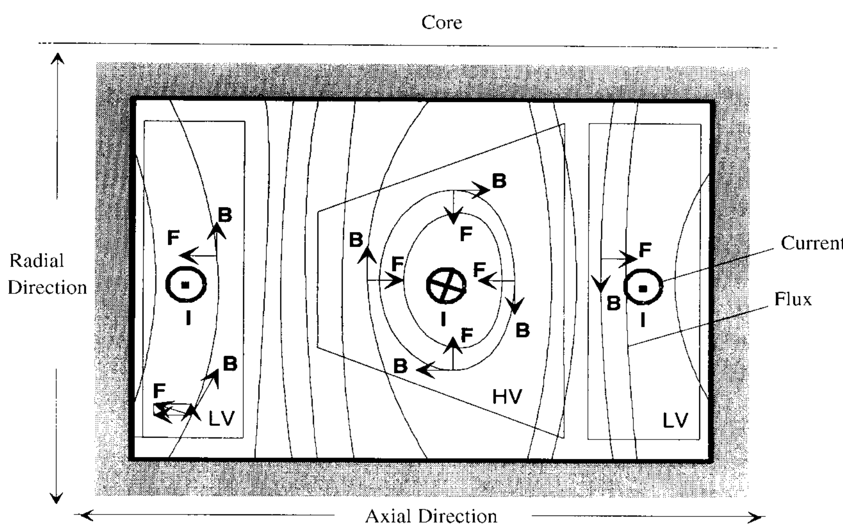


Figure 2.3 Generated Forces in a Shell Form Transformer

The common failure modes for a shell form transformer are as follows:

- Conductor tilting from cumulative axial force
- Conductor beam bending from generated axial force
- Radial instability of the winding pancakes
- End support collapse (forces transmitted into the core).

The described windings deformations can affect the leakage flux path, which in turn may result in the change of the measured leakage reactance.

How Results are Calculated

Three-phase Equivalent Test

The resulting leakage reactance in % is calculated as follows:

$$\%X = [(1/60)\Sigma X_M][S_{3\varphi}(\text{in kVA})/V^2_{L\text{-}L}(\text{in kV})]$$

where

ΣX_M – sum of the individual reactances of each phase, measured in ohms

$S_{3\varphi}$ base three-phase power of the winding where the measurements are performed, obtained from the transformer nameplate

$V^2_{L\text{-}L}$ – base line-to-line voltage of the winding where the measurements are performed, obtained from the nameplate

Per-phase Test

The resulting leakage reactance in % is calculated as follows:

- For test performed from a delta-connected winding

  $$\%X = [(1/30)][S_{3\varphi}\ (\text{in kVA})/\ V^2_{L\text{-}L}\ (\text{in kV})]$$

- For test performed from a wye-connected winding

  $$\%X = [(1/10)\ X_M][S_{3\varphi}\ (\text{in kVA})/\ V^2_{L\text{-}L}\ (\text{in kV})]$$

where:

X_M – measured reactance in ohms

$S_{3\varphi}$ – base three-phase power of the winding where the measurements are performed, obtained from the transformer nameplate

$V_{L\text{-}L}$ – base line-to-line voltage of the winding where the measurements are performed, obtained from the transformer nameplate.

- For the test performed from the zig/zag-connected winding, the results are analyzed in ohms without conversion into %

Single-phase Two-winding Test

The resulting leakage reactance in % is calculated as follows:

$$\%X = [(1/10)\ X_M][S(\text{in kVA})/V^2(\text{in kV})]$$

where X_M is the measured reactance ohms, and S and V are the base power and voltage of the winding where the measurements are performed, obtained from the transformer nameplate.

3. Leakage Reactance Test Procedures

Test Considerations

There are two options being offered for measuring leakage reactance using the M4000. The M4130 Leakage Reactance Module requires the use of an external user-supplied variac and user-supplied current cables. The M4110 Leakage Reactance Interface includes all controls, cables, and safety interlocks, and the Leakage Reactance Module in a single package. Following are instructions for use of the M4110.

In addition to the M4000, it is necessary to have the following equipment for Leakage Reactance Testing:

- Doble Leakage Reactance Interface, including
- Set of M4110 Voltage Source Cables
- Set of M4110 Voltage Sense Cables
- M4110 Ground Cable
- A set of heavy jumper cables for short-circuiting the Low Voltage winding
- The M4110 leakage reactance software module for the M4000

If using the M4130 Leakage Reactance Module, a variac and three cables are required to connect the variac autotransformer to the transformer bushings and the Leakage Reactance Module. The size of the cable must be in accordance with the variac rating. Note that the M4130 Leakage Reactance Module is rated 400 volts, 50 amperes. The M4130 is supplied with voltage sense cables and a DC power supply cable.

Information Needed Before Running a Test

Although it is possible to run a test without any transformer nameplate information or benchmark data, % Reactance and % Impedance cannot then be calculated. Transformer nameplates include the following information which should be entered into the M4000 program prior to running a test:

- Percent Impedance
- Base VoltAmperes (in MVA) for this impedance
- Base Line-to-Line voltage (in kV) for this impedance
- Tap positions for which the nameplate values were obtained

NOTE

For Single Phase transformers only, the Base Voltage in kV should be the Line-to-Ground, and not the Line-to-Line, kV.

If available from previous testing the following additional benchmark information should be entered:

- Benchmark percent impedance
- Benchmark percent reactance

If not, use the nameplate impedance in these fields.

Test Voltages

The objective is to select a voltage sufficient to allow an accurate measurement of the leakage reactance. The source can be a 120 or 240 volts outlet. The M4000 Leakage Reactance Interface can deliver a maximum test current of 25 amperes for 3-5 minutes before tripping the output circuit breaker. Its maximum continuous output current rating is 9.5 amperes. It is equipped with a thermal shutdown circuit that prevents the output from being energized in the event the variac autotransformer temperature has exceeded the safe operating limit. The red overload light indicates overload.

If using the M4130 Leakage Reactance Module, choose a variac with the ratings of the M4130 in mind (50 A, 400V).

Once you enter the transformer nameplate information (Percent Impedance, and kV, MVA, and tap positions on which this number is based) and the benchmark information, the M4000 calculates and suggests a test current. You can then adjust the variac to the recommended test current.

If transformer nameplate information reference information is not available, a test may still be run. However, if using the M4110, you must adjust the variac so as to achieve at least 15 volts on the winding.

CAUTION

Take care to assure all connecting cables are rated for the expected test current. Since one of the windings will be short-circuited for this test, the jumper cables must be rated for the expected current in the short-circuited winding. Although the current cables used to energize a winding will need to carry 25 amperes or less, the jumpers used to short-circuit the opposite winding may be required to carry many times this current.

Selecting the Test Method

The following approach to selecting the test type is recommended.

On a new or rebuilt three-phase transformer or during the initial test on a used transformer, a three-phase equivalent test and per-phase tests should be performed. This allows comparison with the nameplate value (the three phase equivalent test), between the phases (per-phase tests) and provides a benchmark for future tests (per-phase tests). On a single-phase unit, only one test can be performed (Figure 3.3 M4110 Setup (a)). For comparison, tests should be performed on the same LTC positions as the nameplate values.

Once the comparison with the nameplate is verified, follow-up tests can include per-phase tests only. Besides being a more searching test, it allows comparison not only with the previous test results but between the phases as well.

The initial tests should be performed on all the de-energized tap changer positions. It is conceivable that throughout its service life a transformer may be energized in several DETC positions. When units trip off-line, the service personnel may be reluctant to change the DETC positions solely to perform a test in positions in which the initial leakage reactance measurement was performed

Special Considerations

The test performed from the high-voltage winding at a given voltage requires a lower current from the source than the test performed at the same voltage from the low-voltage winding.

It is recommended to perform the test at the highest possible voltage to minimize the effects of the magnetizing reactance. For further information, see Proceedings of the *Sixty Second Annual International Conference of Doble Clients*, 1995, sec. 8-12.1. When nameplate data is available and input to the M4000 software, these test settings are selected for you.

For certain winding configurations, the results of the per-phase will not compare with the nameplate value or results of the three-phase equivalent test. For further information see Proceedings of the *Sixty-Second Annual International Conference of Doble Clients*, *1995*, sec. 8-13.1.

Test Connections

Test connections for use with the M4110 are shown in Figure 3.3 M4110 Setup (a) and Figure 3.4 M4110 Setup (b). Test connections for use with the M4130 are shown in Figure 3.5 M4130 Setup (a) and Figure 3.6 M4130 Setup (b).

NOTE **These test connections represent common transformer winding vector relationships. Always check your transformer nameplate drawing to be sure the phase short-circuited corresponds to the phase energized! The consequence of short-circuiting the wrong winding will be that the tester will not be able to obtain the recommended current to run the test. For example, for a Per-Phase Wye test, a transformer with the following vector representation of its winding relationship would require the different connections shown:**

Table 3.1 Example of Modified Connections for Leakage Reactance Per-Phase Wye Test

Connections Shown In Manual For Per-Phase Wye Test		**Connections Required by Per-Phase Wye Test For Wye-Delta Vector Diagram Shown Below**	
Energize	Short	Energize	Short
H1-H0	X1-X3	H1-H0	X2-X1
H2-H0	X2-X1	H2-H0	X3-X2
H3-H0	X3-X2	H3-H0	X1-X3

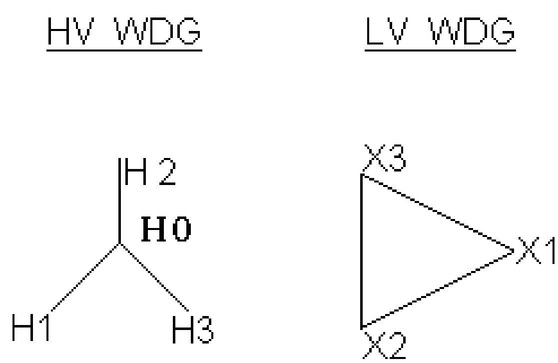


Figure 3.1 Example of Transformer Winding Vector Diagram Requiring Modified Leakage Reactance Test Connections

Test Procedures for a Two-winding Three-Phase Unit

With the M4000 insulation analyzer, which uses single-phase excitation, the leakage reactance of a three-phase unit can be measured using two methods: the three-phase-equivalent test and the per-phase test.

Three-phase Equivalent Test

One test is performed on each phase, by connecting the voltage source and sense leads from the Leakage Reactance Interface to each pair of line terminals. All three line terminals on the opposite winding are connected together with jumpers, as shown on Figure 3.4 M4110 Setup (b) (if using the M4110), and Figure 3.6 M4130 Setup (b) (if using the M4130).

Per-phase Test

One test is performed on each phase, by connecting the voltage (source and sense) leads from the Leakage Reactance Interface to a line and the neutral terminals on wye and zig/zag windings or to a pair of line terminals on a delta winding. The terminals on the opposite winding should be short-circuited, as shown in Figure 3.3 M4110 Setup (a) (if using the M4110), and Figure 3.5 M4130 Setup (a) (if using the M4130).

NOTE

For the Per-Phase tests, use the vector diagram on the transformer nameplate to assure that the phase being short-circuited corresponds to the phase being energized. The examples in the above-mentioned figures may not always correspond to the vector diagrams representing your transformer.

Test Procedures for a Two-winding Single-phase Unit

The test connections for a single-phase unit are shown in Figure 3.3 M4110 Setup (a) or Figure 3.4 M4110 Setup (b) (if using the M4110), and Figure 3.5 M4130 Setup (a) or Figure 3.6 M4130 Setup (b) (if using the M4130).

CAUTION

Be aware of the transformer turns ratio, and the high currents that may result on the short-circuited winding. Be sure the jumper cables are rated for that current!

Test Procedures for a Multi-winding Unit

In a multi-winding (more than two windings) unit, the leakage reactance associated with each pair of windings should be tested. Pick two windings between which you wish to measure the Leakage Reactance, and (after entering the nameplate data corresponding to that winding pair) energize the higher-voltage one while shorting the lower-voltage one in accordance with the connection instructions. The line terminals of the other windings should be left floating. In a three-winding unit, the test procedures described above are applied to three pairs of windings. In a four-winding unit, they are applied to six pairs of windings. The figure below shows the Per-Phase leakage reactance test on one phase between the H and X windings of a three-winding transformer. Tests would then be made between H and Y windings (X floating), and between X and Y (H floating).

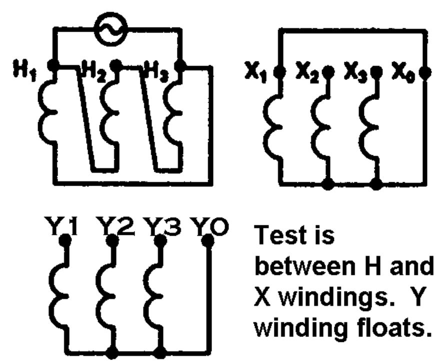


Figure 3.2 Leakage Reactance Test on a Three-Winding Transformer

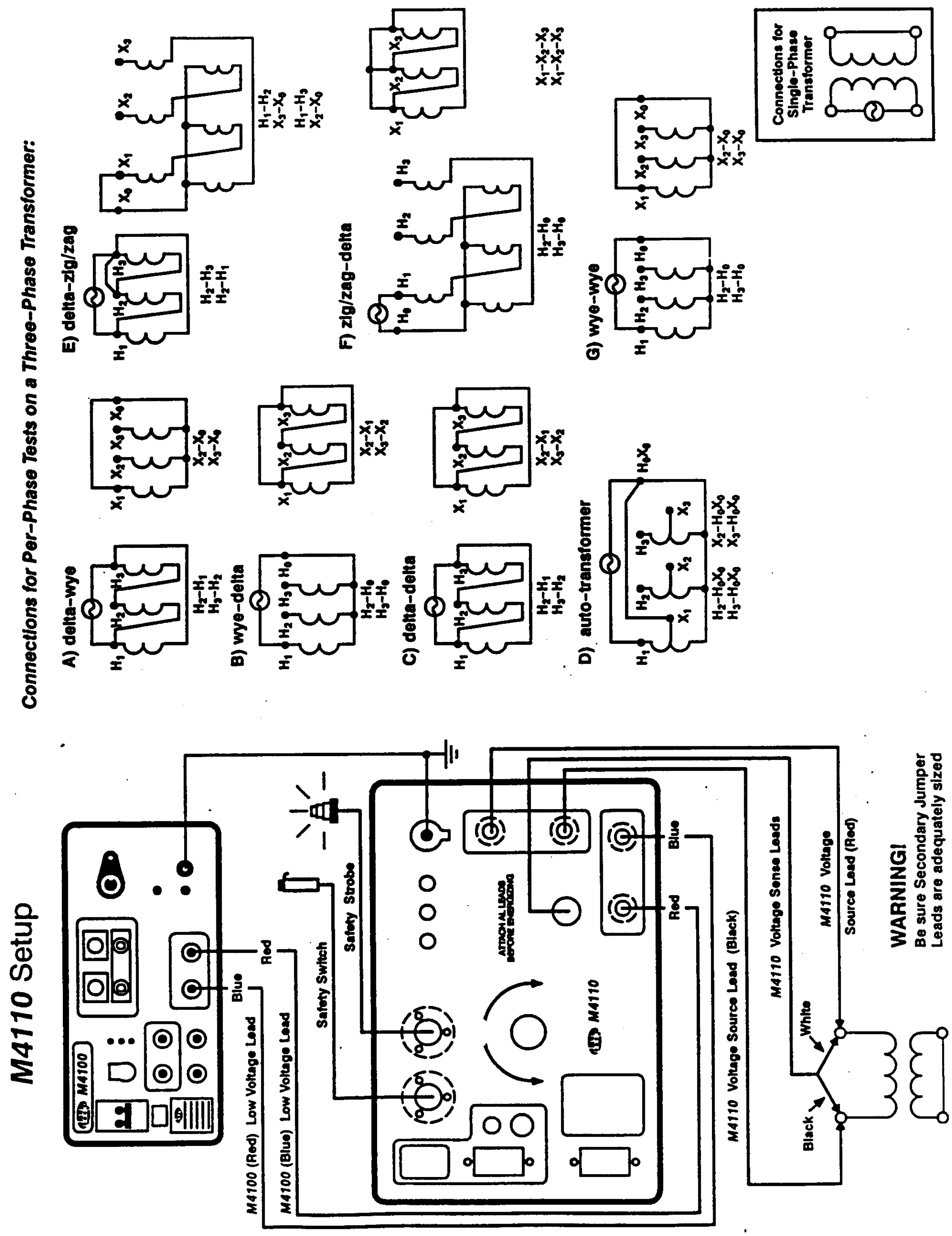


Figure 3.3 M4110 Setup (a)

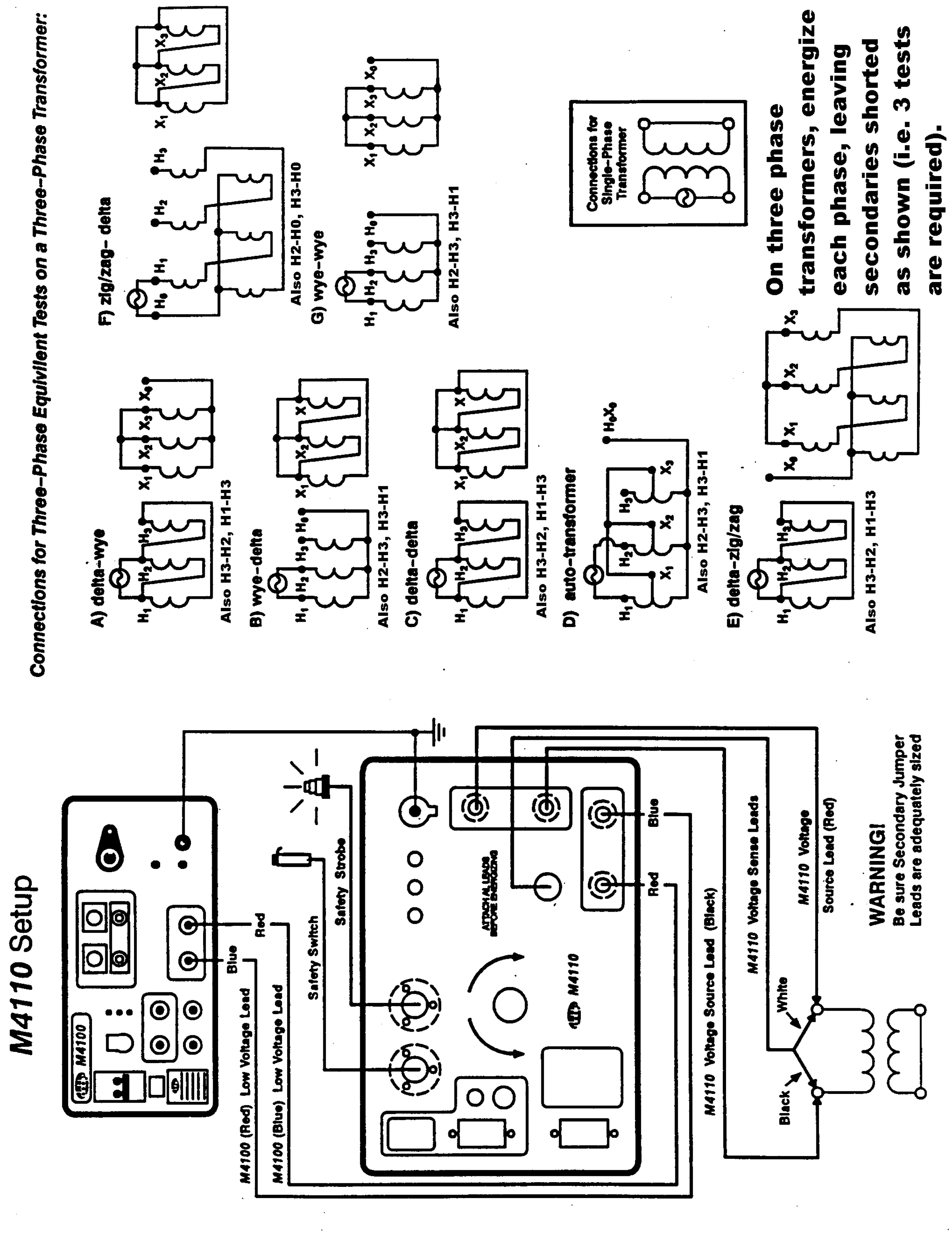


Figure 3.4 M4110 Setup (b)

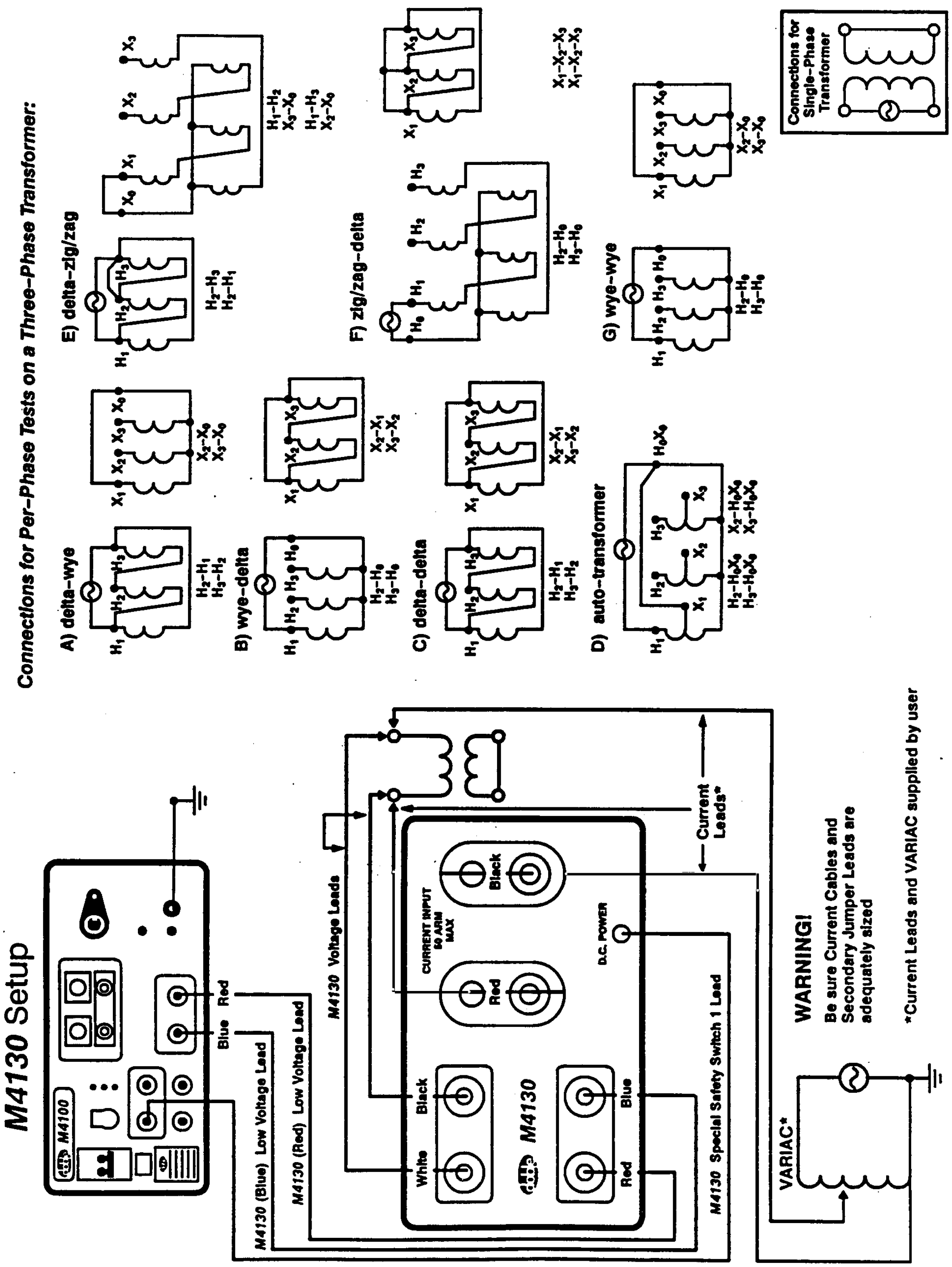


Figure 3.5 M4130 Setup (a)

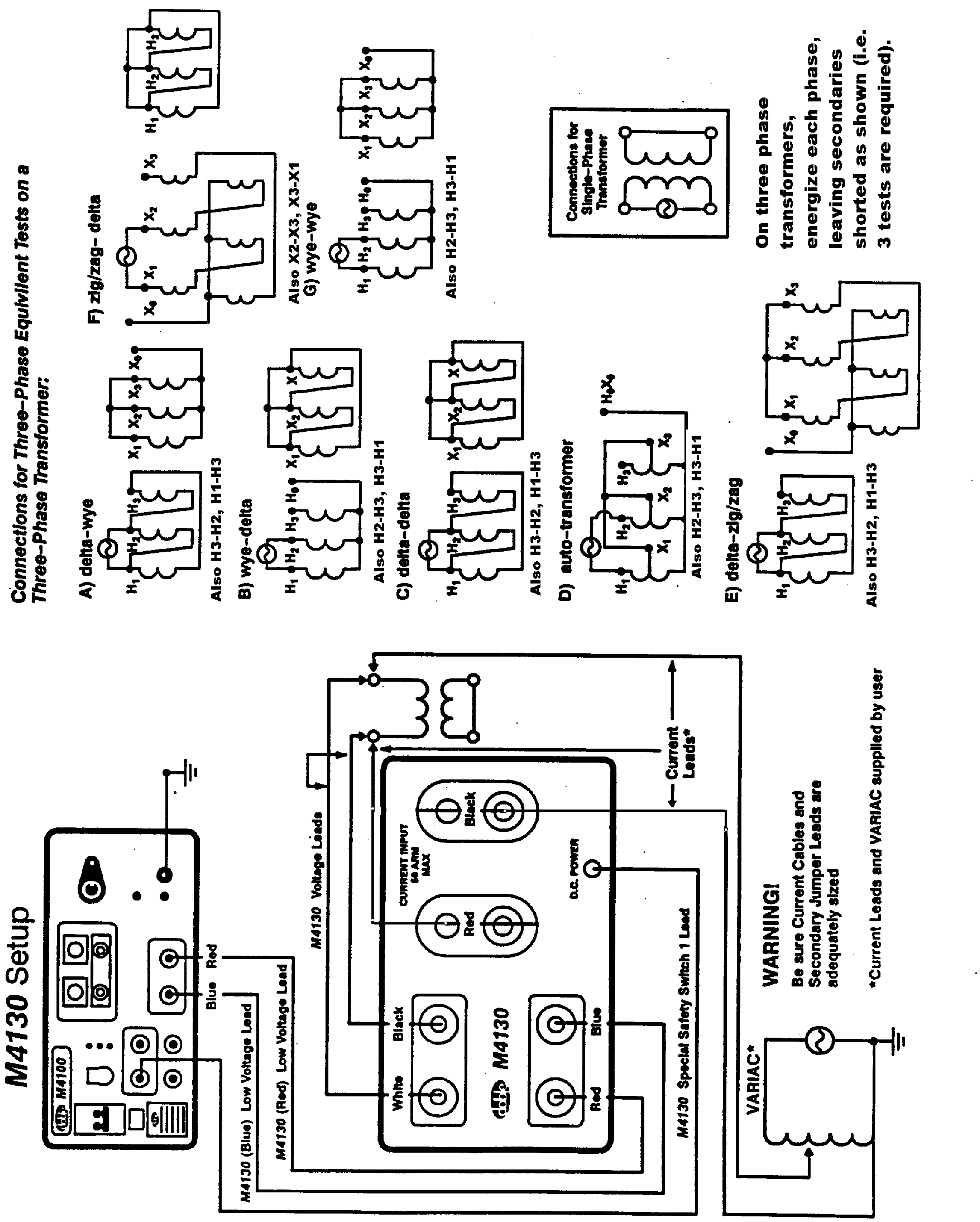


Figure 3.6 M4130 Setup (b)

Test Setup Using the M4110 or the M4130

Use Figure 3.3 M4110 Setup (a), Figure 3.4 M4110 Setup (b), Figure 3.5 M4130 Setup (a), and Figure 3.6 M4130 Setup (b) to select the connection that applies to your transformer winding configuration.

Setup for a Single-phase Transformer Test, M4110

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4110 Leakage Reactance Interface ground cable to ground. Make sure the M4100 and M4110 test ground leads are connected to a common ground point.
3. Connect one end of each of the two voltage source leads across the winding to be energized, and the other end of each to the M4110 Leakage Reactance Interface Voltage Source Terminals. Note that these cables are color coded and must be attached by color to the test set.
4. Connect the black and white clips on one end of the voltage sense cable across the same winding as the voltage source leads. Connect the connector on the other end to the Leakage Reactance Interface Voltage Sense Terminals, observing the color coding of the leads. THE VOLTAGE SOURCE AND VOLTAGE SENSE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE BLACK TERMINALS OF EACH ARE CONNECTED TO THE SAME BUSHING; AND THE RED SOURCE AND WHITE SENSE TERMINALS ARE CONNECTED TO THE OTHER BUSHING.
5. Jumper together the two terminals of the opposite winding (see Figure 3.3 M4110 Setup (a) or Figure 3.4 M4110 Setup (b)).
6. Connect the M4100 safety switch to the M4110 Leakage Reactance Interface.
7. Connect the M4100 safety strobe to the M4110 Leakage Reactance Interface.
8. Connect the Red and Blue leads between the M4100 and the M4110 Leakage Reactance Interface, observing the color coding.
9. Connect the M4200c, the M4100, and the M4110 to your AC power source.

Setup for a Single-phase Transformer Test Using the M4130

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4130 DC power supply cable between the M4130 Leakage Reactance Module and the M4100 Safety Switch #1 connector.
3. Connect the three sections of user-supplied current leads so as to complete a circuit from the user-supplied variac, across the winding to be energized, through the M4130 Leakage Reactance Module, and back to the variac (see Figure 3.5 M4130 Setup (a)).
4. Connect the black and white leads from one end of the voltage cable across the same winding as the current leads, and the leads from the other end to the M4130 Leakage Reactance Module Voltage Input Terminals, observing the color coding of the leads. THE CURRRENT AND VOLTAGE CABLES CONNECTED TO THE BLACK TERMINALS ON THE M4130 MUST BE CONNECTED TO THE SAME TRANSFORMER BUSHING, AND THE CURRENT CABLE CONNECTED TO THE RED M4130 TERMINAL MUST BE CONNECTED TO THE SAME BUSHING AS THE VOLTAGE CABLE CONNECTED TO THE WHITE M4130 TERMINAL (See Figure 3.5 M4130 Setup (a) or Figure 3.6 M4130 Setup (b)).
5. Jumper together the two terminals of the opposite winding (see Figure 3.5 M4130 Setup (a) or Figure 3.6 M4130 Setup (b)).
6. Connect the Red and Blue leads between the M4100 and the M4130 Leakage Reactance Module, observing the color coding.
7. Connect the M4200c and the M4100 to your AC power source.

Setup for a Three-phase Transformer Test Using the M4110

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4110 Leakage Reactance Interface ground cable to ground. Make sure the M4100 and M4110 test ground leads are connected to a common ground point.
3. <u>If performing a Per-Phase test</u>, connect one end of the voltage source leads across a phase of a winding (such as H_3–H_1 or H_3-H_0), and the other end to the M4110 Leakage Reactance Interface Output Terminals, matching the terminal colors to those of the lead connectors. <u>If performing a Three Phase Equivalent test,</u> connect one end of the voltage source leads across two phase terminals (the neutral bushing is not used), and the other end to the M4110 Leakage Reactance Interface Output Terminals, matching the terminal colors to those of the lead connectors

4. Connect one end of the voltage sense leads across the same terminals as the voltage source leads. Connect the other end to the M4110 Leakage Reactance Interface Voltage Input Terminals, observing the color coding of the leads. THE SOURCE AND SENSE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE BLACK CONNECTORS ON THE SOURCE AND SENSE LEADS SHOULD BOTH BE CONNECTED TO THE SAME BUSHING ON THE TRANSFORMER UNDER TEST. ALSO, THE RED SOURCE LEAD AND THE WHITE SENSE LEAD SHOULD BOTH BE CONNECTED TO THE BUSHING ON THE OTHER END OF THE TRANSFORMER WINDING UNDER TEST.
5. **If performing a Per-Phase test**, jumper only the phase of the opposite winding corresponding to the phase under test, as determined by the winding vector diagram on the transformer nameplate, except in the case of a zig-zag winding (see Figure 3.3 M4110 Setup (a)). **If performing a Three-Phase Equivalent Test**, jumper all three line terminals of the opposite winding.
6. Connect the M4100 safety switch to the M4110 Leakage Reactance Interface.
7. Connect the M4100 safety strobe to the M4110 Leakage Reactance Interface.
8. Connect the Red and Blue leads between the M4100 and the Leakage Reactance Interface, observing the color coding.
9. Connect the M4200c, the M4100, and the M4110 to your AC power source.

Setup for a Three-phase Transformer Test Using the M4130

1. Connect the M4100 test set to ground using the ground cable.
2. Connect the M4130 DC power supply cable between the M4130 Leakage Reactance Module and the M4100 Safety Switch #1 connector.
3. If performing a Per-Phase test, connect one end of the voltage source leads across a phase of a winding (such as H_3–H_1 or H_3-H_0), and the other end to the M4130 Leakage Reactance Module Output Terminals, matching the terminal colors to those of the lead connectors. If performing a Three Phase Equivalent test, connect one end of the voltage source leads across two phase terminals (the neutral bushing is not used), and the other end to the M4130 Leakage Reactance Module Output Terminals, matching the terminal colors to those of the lead connectors

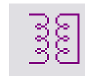
4. Connect one end of the current leads across a phase of a winding (such as H_3–H_1), and the other end to the M4130 Leakage Reactance Module Input Terminals.
5. Connect one end of the voltage leads across the same phase as the current leads. Connect the other end to the M4130 Leakage Reactance Module Voltage Input Terminals, observing the color coding of the leads. THE CURRENT AND VOLTAGE LEADS MUST BE CONNECTED IN SUCH A WAY THAT THE CURRENT LEAD AND THE VOLTAGE LEAD CONNECTED TO THEIR RESPECTIVE BLACK COLORED TERMINALS ON THE M4130 LEAKAGE REACTANCE MODULE SHOULD BOTH BE CONNECTED TO THE SAME BUSHING ON THE TRANSFORMER UNDER TEST. ALSO, THE CURRENT LEAD CONNECTED TO THE RED TERMINAL AND THE VOLTAGE LEAD CONNECTED TO THE WHITE TERMINAL ON THE M4130 LEAKAGE REACTANCE MODULE SHOULD BOTH BE CONNECTED TO THE BUSHING ON THE OTHER END OF THE TRANSFORMER WINDING UNDER TEST.
6. **If performing a Per-Phase test**, jumper only the phase of the opposite winding corresponding to the phase under test, as determined by the winding vector diagram on the transformer nameplate, except in the case of a zig-zag winding (see Figure 3.5 M4130 Setup (a)). **If performing a Three-Phase Equivalent test**, jumper all three line terminals of the opposite winding.
7. Connect the Red and Blue leads between the M4100 and the M4130 Leakage Reactance Module, observing the color coding.
8. Connect the M4200c and the M4100 to your AC power source.

Setup for a Transformer with Three or More Windings

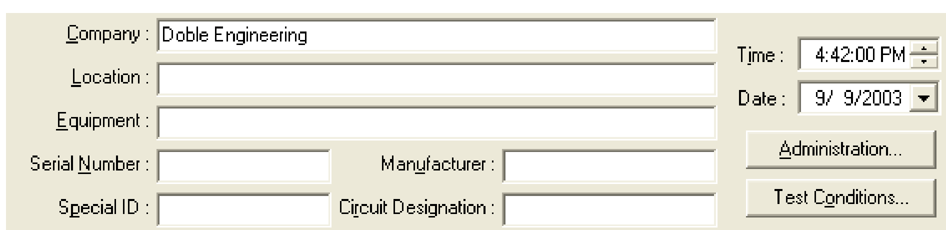
1. Follow the instructions for a two winding transformer
2. Leakage Reactance should be measured between all pairs of windings (H-X, H-Y, X-Y, etc)
3. The windings not under test must be left floating

Running a Test

1. Once the connections are made, turn on the test set.

2. Select *Mode/Leakage Reactance* from the Main Menu bar, or click the Leakage Reactance Icon. 
3. Select the winding configuration. This must be done first, since doing so automatically sets the available test configuration and resulting nameplate data and benchmark data entry fields. If using DTA, this will be automatically filled in on the Leakage Reactance nameplate screen when you enter transformer configuration on the main nameplate screen.
4. Some of the Test Configurations are available for selection only with certain winding configurations. Select a Test Configuration:

Winding Configuration	Test Configurations Available
Single-Phase	Single-Phase
Delta-Wye	Three-Phase Equivalent, Per-Phase Delta, Per-Phase Wye
Delta-Delta	Three-Phase Equivalent, Per-Phase Delta
Wye-Delta	Three-Phase Equivalent, Per-Phase Wye
Wye-Wye	Three-Phase Equivalent, Per-Phase Wye
Delta-Zigzag	Three-Phase Equivalent, Per-Phase Delta, Per-Phase Zigzag
Wye-Zigzag	Three-Phase Equivalent, Per-Phase Wye, Per-Phase Zigzag
Other	Three-Phase Equivalent, Per-Phase, Other



5. Enter transformer identification in the Nameplate Information fields.

To enter this nameplate and benchmark information:

- On the Leakage Reactance form, click the *Benchmark* tab.
- Enter the tap positions (ignore a field if there is no on-load tap changer) on the first available row.
- In the *Phase* column, identify the phase.

- In the *Base Voltamperes (MVA)* and *Base Volts (kV)*, enter the values given on the nameplate.
- In the *Nameplate % Impedance*, enter the nameplate impedance.
- Unless this is the first test, enter the values obtained for the % impedance and % reactance for each phase of the first (benchmark) per-phase tests. If this is the first test, and you have no benchmark data, enter the transformer nameplate impedance in both of these fields, and the results from this first per-phase test will be entered as the benchmark values for all future tests.
- If using DTA, the benchmark data is entered on the Leakage Reactance test screen, with values for % Impedance and % Reactance entered on the screen corresponding to the tab selected below.

6. There will be one nameplate value and one benchmark value per single-phase transformer. The M4000 allows three single-phase tests to be made on a single screen, in the event the user is testing a bank of three single-phase transformers. When *Winding Configuration* is selected as *Single,* the letter next to the *Serial Number* field indicates which single phase transformer is being identified. Click the button to advance the display to the next serial number.

7. The three-phase equivalent test will have one nameplate value and one benchmark value.

8. The per-phase-delta (or wye) will both have one nameplate value and three benchmark values, one per phase.

NOTE

For all but the single phase transformers, base voltage must be line-to-line; for single phase transformers, it must be line-to-ground.

9. Enter information in the Administration and Test Conditions buttons as needed.

10. Depending on the selected Test Configuration, there may be up to three rows (phases) where test data will be entered. Make sure the desired row in the Phase column is filled in before testing, in order to identify the terminals energized and the terminals shorted for the record. When starting a test, you will be asked which row (phase) you are testing.

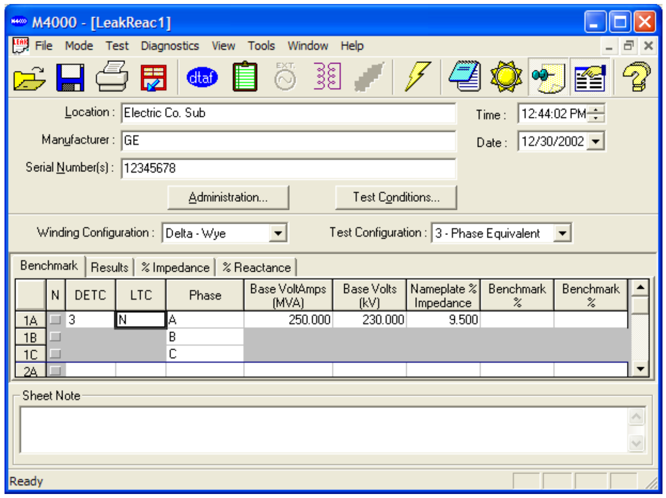


Figure 3.7 Leakage Reactance Test Nameplate Data

11. To begin the test, press F2 or click the lightning bolt icon. If the Nameplate data has not been entered, you will be presented with a final warning screen before you start the test.

WARNING

If using the M4130 Leakage Reactance Module, the safety switches and safety strobe are not used! Observe necessary safety precautions!

12. Adjust the variac until the value of current opposite the analog current bar on the screen falls in or as near as possible to the recommended test current range. The test voltage should exceed at least 15 volts.

13. Press the F3 key to measure. The message, “Do not change voltage; collecting data” will be displayed.

14. When the M4000 has made the necessary measurements, the message, “Test Done” will be displayed.

15. Press F5 to accept the results, or any of the other keys whose functions are described at the bottom of the screen:

F1	Screen Help
F2	Restart Test
F5	Accept Results
F6	Discard Results
F7	Print Results
F8	Save Results

16. Repeat the test for each phase of the winding, making sure the correct column is highlighted before starting.
17. Start a new Leakage Reactance form for each pair of windings being tested. You will need three forms for a three-winding transformer, and six for a four winding transformer.

4. Interpretation of Test Results

There are three tabs which show test results: the *Results* tab shows many of the measured variables. The main analysis is done with the data in the % *Impedance* and % *Reactance* tabs. Besides the measured and benchmark values, they contain the Delta Benchmark and Delta Average values. The analysis depends on whether the test is an initial or a subsequent one. During the initial test, both the three-phase equivalent and the per-phase measurements are performed. The subsequent test (with some exceptions, discussed below) requires only the per-phase measurements.

The factory data are usually expressed in terms of the average short-circuit impedance. Therefore, they should be compared with the impedance value measured in the field using the three-phase equivalent measurement. The comparison between the initial and subsequent tests should be performed on the basis of the per-phase leakage reactance test results. For transformers whose nameplate impedance is less than 5% and whose power rating is less than or equal to 500 KVA, the tester should perform only the per phase test and its results analysis, and not the three phase equivalent.

Initial Test

The objective of the initial test is twofold: to compare results with factory data and to establish a benchmark for subsequent tests. The purpose of the three-phase equivalent test is to produce results for comparison with the factory data (*Delta Benchmark*, if the factory nameplate impedance was used as a benchmark value). When results are not within 3% of the nameplate values, the explanation may lie in different instrumentation and test setups (a different de-energized tap was used), difference in flux distribution under the three- and single-phase excitation, and/or the presence of the winding distortion. The latter can be confirmed through the per-phase test, where the comparison between phases (*phase pattern*) may help to explain the difference between factory and field results. The average value of the three per-phase impedances is calculated, and the percentage difference between each per-phase value and this average is show in the *Delta Average* column. If each of the three phases is within 3% of their average value, the winding distortion most likely is not an issue. For the single-phase units (for obvious reasons), all the analyses are based on the per-phase measurements only.

Typically, the results of the per-phase measurements are used as a benchmark for subsequent measurements. On some units, however, the per-phase results are influenced by the reluctance of the leakage flux path outside the leakage channel (due to the peculiarities of the single-phase excitation), thus masking the changes in the leakage channel. Under these conditions, all three per-phase values may exceed the factory data by as much as 10-30%, while the three-phase equivalent test may be comparable with the factory data. Therefore, in these cases the results of the three-phase equivalent measurement may be used as a benchmark for subsequent tests.

In a three-winding unit, the sign of a change in leakage reactance associated with three pairs of windings can be used to identify the distorted winding. These limits simply state whether the distortion is present. The real challenge is in defining the limits that, if not exceeded, will allow the unit to remain in service even with distorted windings. At the same time, the same percent change in the measured leakage reactance can be caused by different levels of distortion in different transformers. Therefore, these limits may be different for different transformer designs. In the meantime, experience suggests that a winding distortion could be suspected if both the three-phase equivalent results deviate from the factory data, and the per-phase results deviate from each other by more than 3% of the measured value.

In conclusion, the *Delta Benchmark* is generally used for the initial test data analysis, using the three phase equivalent test, and for subsequent tests, using the per-phase tests. The *Delta Average* is used mainly for the initial per-phase test, before a real benchmark for these values has been established.

Subsequent Test

During the subsequent test, results of the per-phase test or (if applicable) the three-phase equivalent test are compared with results of initial (benchmark) measurements. We recommend treating changes exceeding 2% of the leakage reactance measured during the initial tests as an indication of winding distortion.

Appendix A. Voltage Selection

Altering the Voltage Rating from 115 Volts to 230 Volts

1. Remove the screws in the top panel of the M4110. There are six screws to be removed. Use Allen keys of British dimensions; metric may not work. Also, loosen two screws in the black knob on the rheostat control. Lift off the knob.
2. The top panel should now easily lift up. The Teflon guide on the rheostat rod is part of the top panel and does not need to be removed. If the top panel does not lift, apply only a slight pressure to release it.

NOTE

DO NOT REMOVE ANY SCREWS AT THE SIDES OF THE M4110. ONLY THE SIX TOP SCREWS AND RHEOSTAT KNOB SCREWS ARE TO BE TOUCHED

The Rheostat knob screws only need to be loosened, not removed from the knob.

3. On the underside of this top panel there is a terminal strip.
4. For 115 Volts there is a yellow wire connecting to a yellow wire. To change to 220 Volts, **move the yellow wire to the white wire** right next to this yellow wire. This white wire won't have another wire connected to it (if it is set to 115 Volts)

   When you are finished the yellow wire will be attached to the white wire.
5. Next, change the 115 Volt switch from the 115 Volt setting to the 220 Volt setting:

This switch is on the "Relay PCB" which is attached to the Variac. This PCB is very difficult to remove so don't remove it. You will see this switch from the side of the PCB. Slide your finger down to the PCB and switch it to the alternate position (which will be the 220 Volt setting). If the wire in step 4.) above is set to 115 Volts, then this switch has to be switched as well. Note that the use of a dentist mirror will assist to verify the setting of the switch before you change it, and afterwards, to be sure it was indeed changed. You will see the voltage setting as a number in the mirror. Remember that the mirror will cause the number to show backwards or the switch may be upside down.

6. If possible, change the nameplate with a metal stamp to indicate that the voltage rating has been changed, or contact Doble to order a new nameplate. Identify the unit to Doble by its serial number. Use a marker of some type to temporarily correct the nameplate if necessary. Do not leave the set with an incorrect voltage rating on the nameplate.
7. Change the supply cord plug to a plug recognized in your country for use at 230 Volts, unless you are using the power supply cord supplied by Doble to connect to the transporter system voltage plug-in supply.

Appendix B. Part Numbers

Doble part numbers of replaceable M4110 Leakage Reactance Interface components are provided in this appendix.

Description	Part Number	Quantity
Revision Level C		
Bag, Cable, Small	2FB-3450-01	1
Cable, Leakage Reactance, M4100	05B-0504-02	1
Cable, High Current, Black	05B-0584-01	1
Cable, High Current Red	05B-0584-02	1
Cable, Ground, 30’ M2H, MEU	02C-0019-01	1
Power Cord, 6 Ft., #14/3	181-0452	1
M4100 LR Interface, S/W & Documents	071-0032-01	1

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