The VOLTECH Handbook of Transformer Testing
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1. Transformer Basics

1.1 Basic Transformer Theory

Figure 1 represents the essential elements for a transformer - a magnetic core, with a primary and secondary coil wound on the limbs of the magnetic core.

An alternating voltage ($V_p$) applied to the PRIMARY creates an alternating current ($I_p$) through the primary. This current produces an alternating magnetic flux in the magnetic core.

This alternating magnetic flux induces a voltage in each turn of the primary and in each turn of the SECONDARY.
As the flux is a constant e.g. the same in both primary and secondary: -

\[ V_p = const \times N_p \]
\[ V_s = const \times N_s \]

\[ \therefore \frac{V_s}{V_p} = \frac{N_s}{N_p} \]

This equation shows that a transformer can be used to step up or step down an ac voltage by controlling the ratio of primary to secondary turns. (Voltage transformer action).

It can also be shown that: -

Primary VoltAmperes = Secondary VoltAmperes

\[ V_p I_p = V_s I_s \]

\[ \therefore I_s = \frac{V_p}{V_s} I_p \]

As \[ \frac{V_p}{V_s} = \frac{N_p}{N_s} \], we can write: -

\[ I_s = \frac{N_p}{N_s} I_p \]

\[ \therefore \frac{I_s}{I_p} = \frac{N_p}{N_s} \]
This equation shows that a transformer can be used to step up or step down an ac current by controlling the ratio of primary to secondary turns. (Current transformer action)

It will be noted that there is no electrical connection between the primary and secondary windings. A transformer therefore provides a means of isolating one electrical circuit from another.

These features - voltage/current transformation and isolation, cannot be obtained efficiently by any other means, with the result that transformers are used in almost every piece of electrical and electronic equipment in the world.
1.2 B-H Curves

When the primary of a transformer is energized with the secondary unloaded, some small current flows in the primary. This current creates a 'magnetizing force' that produces the magnetic flux in the transformer core.

The magnetizing force (H) is equal to the product of magnetizing current and the number of turns, and is expressed as Ampere - Turns.

For any given magnetic material, the relationship between magnetizing force and the magnetic flux produced can be plotted, and this is known as the B-H curve of the material.

See Figure 2

\[
\begin{align*}
B \text{ (Flux Density - Tesla or Gauss)} & \quad +\text{ve flux} \\
-\text{ve current} & \quad +\text{ve current} \\
-\text{ve flux} & \quad H \text{ (Magnetizing force - ampere turns/metre or Oersteds)}
\end{align*}
\]

Figure 2
From the B-H curve it can be seen that as the magnetizing force is increased from zero, the flux increases up to a certain maximum value of flux. Above this level, further increases in magnetizing force result in no significant increase in flux. The magnetic material is said to be 'saturated'.

A transformer is normally designed to ensure that the magnetic flux density is below the level that would cause saturation. The flux density can be determined using the following equation:

\[ E = 4.44 N B A f \]

\[ B = \frac{E}{4.44 N A f} \]

Where:

- \( E \) represents the rms value of the applied voltage.
- \( N \) represents the number of turns of the winding
- \( B \) represents the maximum value of the magnetic flux density in the core (Tesla)
- \( A \) represents the cross-sectional area of the magnetic material in the core (sq. metres)
- \( f \) represents the frequency of the applied volts

**Note**

1 Tesla = 1 weber/metre
1 weber/m² = 10000 gauss
1 ampere-turn per metre = 4 x 10^{-3} Oersteds
In practice, all magnetic materials, once magnetized, retain some of their magnetization even when the magnetizing force is reduced to zero.

This effect is known as 'remanence' and results in the B-H curve for the material exhibiting a response to a decreasing magnetizing force that is different to the response to an increasing magnetizing force.

In practice, then real magnetic materials have a B-H curve as follows in Figure 3:

The curve shown above is termed the 'hysteresis' loop of the material, and represents the true B-H response of the material. (The B-H curve shown in figure 2 represented the average or mean of the true B-H loop response).
The slope of the B-H curve, the saturation level and the size of the hysteresis loop are dependent on the type of material used, and on other factors. This is illustrated using the following examples: -

**Figure 4**

- **Low-grade Iron core**
- High saturation flux density
- Large loop = Large Hysteresis loss
- Suitable for 50/60H

**Figure 5**

- **High grade iron core**
- High saturation flux density
- Medium loop = Medium Hysteresis loss
- Suitable for 400Hz transformers
Ferrite core - no air gap
Medium saturation flux density
Small loop = Small Hysteresis loss
Suitable for high frequency
Transformers

Ferrite core - large air gap
Small loop = Small Hysteresis loss
Suitable for high frequency Inductors with large dc current.
1.3 Hysteresis loss

Hysteresis loss is the result of cycling the magnetic material along its B-H curve (as shown in figure 3); it represents the energy taken as the applied voltage aligns magnetic dipoles first in one direction and then in the other. The loss increases with the area of the B-H curve enclosed. As the material is driven closer to saturation, both the area within the curve, and the corresponding energy loss each cycle, increase substantially.

1.4 Eddy Current loss

Eddy-current loss is caused by small currents circulating within the core material, stimulated by the alternating flux in the core. The $I^2R$ power loss associated with these currents produces heating of the core known as eddy current loss. In iron cored transformers, insulated iron sheets known as laminations are used to minimise this effect, by restricting the path for circulating currents. Ferrite cores restrict these paths even further.
1.5 Transformer Equivalent Circuit

An ideal transformer with one primary winding and two secondary windings, can be represented as shown in fig 9.

Such a transformer has the following characteristics:

* No losses
* Perfect coupling between all windings
* Infinite open circuit impedance (e.g. no input current when secondaries are open-circuited)
* Infinite insulation between windings
In reality, practical transformers show characteristics that differ from those of an ideal transformer.

Many of these characteristics can be represented by a transformer equivalent circuit:

The equivalent circuit can be easily understood by considering each of these characteristics separately.
1.6 Self-Resonant Frequency

Practical inductive components are not perfect inductors; they have stray resistances and capacitances associated with them. For certain components, especially those with a low inductance value, the impedance of the stray capacitance can become significant when compared to that of the inductance.

\[ X_L = 2\pi f_L \quad X_C = \frac{1}{2}\pi f_C \]

At a sufficiently high frequency, the capacitive impedance can dominate, making a measurement of the inductance impossible. Under these circumstances, any measurement instrument may report negative inductance values and measurement errors. Should these symptoms be observed, reduce the test frequency to avoid problems.

The frequency at which the inductive impedance equals the capacitive impedance \((X_L = X_C)\) is known as the self-resonant frequency (SRF) of the component. At this point, the phase angle of the impedance (which can be measured using the ANGL test) is zero. At test conditions where the frequency is low enough for problems with capacitive impedance to be negligible, the phase angle will be positive and close to 90 degrees.

Therefore, an ANGL test can be used during program development to confirm if measurement problems are due to the chosen test frequency approaching the SRF of the part under test. If the angle is significantly less than 90 degrees, consider reducing the test frequency.

Note that stray fixture capacitance will add to the capacitance of the component and reduce the SRF. Performing compensation will remove the effect of stray fixture capacitance on the measurement of capacitance, but cannot remove its effect on SRF.
## 2. Available Tests, Where Used and Measurement Conditions

### 2.0 Available Tests on the AT Series

The following table summarizes the tests available for the AT5600 and indicates where they might be used:

<table>
<thead>
<tr>
<th>TEST</th>
<th>DESCRIPTION</th>
<th>Main Application</th>
<th>Winding Tested</th>
<th>Reason for Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTY</td>
<td>Continuity</td>
<td>All transformers</td>
<td>All windings</td>
<td>Properly installed fixture</td>
</tr>
<tr>
<td>R</td>
<td>DC Resistance</td>
<td>All transformers</td>
<td>All windings</td>
<td>Properly installed fixture. Correct wire used. Integrity of terminations</td>
</tr>
<tr>
<td>LS</td>
<td>Inductance (Series circuit)</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Correct primary turns. Right grade of core material. Core correctly assembled</td>
</tr>
<tr>
<td>LP</td>
<td>Inductance (Parallel circuit)</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Correct primary turns. Right grade of core material. Core correctly assembled</td>
</tr>
<tr>
<td>QL</td>
<td>Quality Factor</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Right grade of core material. Core correctly assembled. Check for shorted turns</td>
</tr>
<tr>
<td>RLS</td>
<td>Equivalent Series Resistance</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Right grade of core material. Core correctly assembled. Check for shorted turns</td>
</tr>
<tr>
<td>RLP</td>
<td>Equivalent Parallel Resistance</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Right grade of core material. Core correctly assembled. Check for shorted turns</td>
</tr>
<tr>
<td>D</td>
<td>Dissipation Factor</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Right grade of core material. Core correctly assembled. Check for shorted turns</td>
</tr>
<tr>
<td>LL</td>
<td>Leakage Inductance</td>
<td>SMPS transformers. Communication Transformers. Others as applicable</td>
<td>Selected windings</td>
<td>Check windings have been installed in the correct position relative to the core</td>
</tr>
<tr>
<td>C</td>
<td>Interwinding Capacitance</td>
<td>High frequency transformers. Isolating transformers</td>
<td>Selected windings</td>
<td>Check winding positioning. Check insulation thickness between windings</td>
</tr>
<tr>
<td>TR</td>
<td>Turns Ratio and Phasing</td>
<td>Most transformers, but usually not line frequency transformers</td>
<td>All windings</td>
<td>Check windings have correct turns and phasing</td>
</tr>
<tr>
<td>TRL</td>
<td>Turns Ratio by Inductance</td>
<td>As with Turns Ratio but used where there is poor flux linkage between windings.</td>
<td>All windings</td>
<td>Check windings have correct turns and phasing</td>
</tr>
<tr>
<td>LVOC</td>
<td>Low Voltage Open Circuit</td>
<td>Usually line frequency transformers</td>
<td>All other windings</td>
<td>Correct secondary turns. Correct phasing</td>
</tr>
<tr>
<td>IR</td>
<td>Insulation Resistance</td>
<td>All transformers</td>
<td>Between selected windings</td>
<td>Winding isolation check where safety is not involved</td>
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<td>--------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>LSB</td>
<td>Inductance with Bias Current (Series Circuit)</td>
<td>Transformers for use in applications where passing significant (dc) bias current is part of the normal operation</td>
<td>One winding</td>
<td>Correct number of turns. Right grade of core material. Core correctly assembled.</td>
</tr>
<tr>
<td>LPB</td>
<td>Inductance with Bias Current (Parallel Circuit)</td>
<td>Transformers for use in applications where passing significant (dc) bias current is part of the normal operation</td>
<td>One winding</td>
<td>Correct number of turns. Right grade of core material. Core correctly assembled.</td>
</tr>
<tr>
<td>OUT</td>
<td>Output To User Port</td>
<td></td>
<td></td>
<td>Allows the AT to perform external switching as part of the test program.</td>
</tr>
<tr>
<td>R2</td>
<td>DC Resistance Match</td>
<td>SMPS, audio &amp; telecom</td>
<td>All windings</td>
<td>Checks matching between windings</td>
</tr>
<tr>
<td>L2</td>
<td>Inductance Match</td>
<td>SMPS, audio &amp; telecom transformers</td>
<td>All windings</td>
<td>Checks matching between windings</td>
</tr>
<tr>
<td>C2</td>
<td>Capacitance Match</td>
<td>SMPS, audio &amp; telecom transformers</td>
<td>All Windings</td>
<td>Checks correct winding position on bobbin</td>
</tr>
<tr>
<td>GBAL</td>
<td>General Longitudinal Balance</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks common mode rejection ratio</td>
</tr>
<tr>
<td>LBAL</td>
<td>Longitudinal Balance</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks common mode rejection ratio</td>
</tr>
<tr>
<td>ILOS</td>
<td>Insertion Loss</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks losses within the transformer</td>
</tr>
<tr>
<td>RESP</td>
<td>Frequency Response</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks losses over a range of frequencies</td>
</tr>
<tr>
<td>RLOS</td>
<td>Return Loss</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks losses returned by a transformer</td>
</tr>
<tr>
<td>Z</td>
<td>Impedance</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks impedance at a given frequency</td>
</tr>
<tr>
<td>ZB</td>
<td>Impedance + bias</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Checks impedance at a given frequency</td>
</tr>
<tr>
<td>ANGL</td>
<td>Impedance Phase Angle</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Finds phase shift between Voltage and Current on a winding.</td>
</tr>
<tr>
<td>PHAS</td>
<td>Interwinding Phase Test</td>
<td>Audio &amp; telecom transformers</td>
<td>Selected Windings</td>
<td>Measures phase shift between a pair of windings</td>
</tr>
<tr>
<td>TEST</td>
<td>DESCRIPTION</td>
<td>Main Application</td>
<td>Winding Tested</td>
<td>Reason for Test</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------</td>
<td>-------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>HPDC</td>
<td>Hi-Pot (DC)</td>
<td>All transformers especially those used for safety insulation</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>HPAC</td>
<td>Hi-Pot (AC)</td>
<td>All transformers especially those used for safety insulation</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>ACRT</td>
<td>Hi-Pot Ramp (AC)</td>
<td>All transformers especially those used for safety insulation</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>DCRT</td>
<td>Hi-Pot Ramp (DC)</td>
<td>All transformers especially those used for safety insulation</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>ACVB</td>
<td>Voltage Breakdown (AC)</td>
<td>Transformers with MOV fitted</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>DCVB</td>
<td>Voltage Breakdown (DC)</td>
<td>Transformers with MOV fitted</td>
<td>Between selected windings usually primary to secondary, screens and core</td>
<td>High voltage safety insulation</td>
</tr>
<tr>
<td>WATT</td>
<td>Wattage</td>
<td>50Hz Iron core transformers</td>
<td>One winding</td>
<td>Correct core material. Properly assembled</td>
</tr>
<tr>
<td>ILK</td>
<td>Leakage Current Test</td>
<td>Medical applications</td>
<td>Between Primary and Secondary Windings</td>
<td>Checks for a common mode current due to capacitance</td>
</tr>
<tr>
<td>STRW</td>
<td>Stress Wattage</td>
<td>Line frequency &amp; High Frequency Transformers</td>
<td>One Winding (Usually the primary)</td>
<td>Checks integrity of inter-turn insulation, the magnetic material and joints</td>
</tr>
<tr>
<td>SURG</td>
<td>Surge Stress Test</td>
<td>All transformers, especially those using fine wire</td>
<td>Selected windings</td>
<td>To identify shorted turns</td>
</tr>
<tr>
<td>MAGI</td>
<td>Magnetising Current</td>
<td>Usually line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Correct primary turns Correct core material properly assembled</td>
</tr>
<tr>
<td>VOC</td>
<td>Open Circuit Voltage</td>
<td>Usually line frequency transformers</td>
<td>All other windings</td>
<td>Correct secondary turns. Correct phasing</td>
</tr>
</tbody>
</table>
### 3. DC1000

<table>
<thead>
<tr>
<th>TEST</th>
<th>DESCRIPTION</th>
<th>Main Application</th>
<th>Winding Tested</th>
<th>Reason for Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSBX</td>
<td>Inductance with External Bias (Series Circuit)</td>
<td>Wound components that usually carry a significant DC Bias current in normal operation.</td>
<td>Selected Windings</td>
<td>Checks number of turns, right grade of correctly assembled core material, where bias current is greater than LSB test can handle.</td>
</tr>
<tr>
<td>LSBX</td>
<td>Inductance with External Bias (Parallel Circuit)</td>
<td>Wound components that usually carry a significant DC Bias current in normal operation.</td>
<td>Selected Windings</td>
<td>Checks number of turns, right grade of correctly assembled core material, where bias current is greater than LPB test can handle.</td>
</tr>
<tr>
<td>ZBX</td>
<td>Impedance with External Bias</td>
<td>Audio &amp; Telecom</td>
<td>Selected Windings</td>
<td>Checks impedance at a given frequency, while applying a greater bias current than is possible with ZB test.</td>
</tr>
</tbody>
</table>

### 4. AC I/F

<table>
<thead>
<tr>
<th>TEST</th>
<th>DESCRIPTION</th>
<th>Main Application</th>
<th>Winding Tested</th>
<th>Reason for Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAGX</td>
<td>MAGI (External Source)</td>
<td>Usually line frequency transformers</td>
<td>One winding, usually the primary</td>
<td>Correct primary turns. Correct core material properly assembled.</td>
</tr>
<tr>
<td>VOCX</td>
<td>VOCX (External Source)</td>
<td>Usually line frequency transformers</td>
<td>All other windings</td>
<td>Correct secondary turns. Correct phasing.</td>
</tr>
<tr>
<td>WATX</td>
<td>WATT (External Source)</td>
<td>50Hz Iron core transformers</td>
<td>One winding</td>
<td>Correct core material. Properly assembled.</td>
</tr>
<tr>
<td>STRX</td>
<td>STRW (External Source)</td>
<td>Line frequency &amp; High Frequency Transformers</td>
<td>One Winding (Usually the primary)</td>
<td>Checks integrity of inter-turn insulation, the magnetic material and joints.</td>
</tr>
</tbody>
</table>
2.1 CTY - Continuity

**Where Used**
The continuity test is available to be placed as the first test in the program to check that the transformer has been inserted correctly into the test fixture.

The test checks that every winding has a resistance less than a user specified limit, with the same limit being applied to all windings. The CTY test is an alternative to using an R (Winding Resistance) test on each winding separately. The CTY test has the advantage of speed of execution; but with the R test, individual limits can be applied to each winding, and manufacturing faults such as the use of the wrong wire gauge can be identified. If you choose to use it, the continuity test will be quicker to execute than a series of resistance tests applied to each winding.

**Specifying the Test Limit**
When specifying the test limit, remember that the same limit is applied to each winding, so you must choose a value higher than the resistance of the biggest winding. For most transformers, where the winding resistances are less than 1 kΩ, a test limit of 10 kΩ should be used, as this will give the quickest test execution.
2.2 R – Winding Resistance

R1, R2, and R3 represent the resistance of the copper wire used to wind the transformer.
When current flows in the windings the resistance causes losses in the windings ($I^2R$ losses), and generates heat.

In addition, the winding resistances cause a voltage drop in the windings when current flows, causing the output voltage to fall with increasing load. (This effect is known as 'Regulation').

Where Used
The measurement of the resistance of all windings should generally be the first group of tests carried out for any type of transformer. It checks that the wire is of the correct diameter, and has not been over-tensioned during winding. The measurement also confirms that the connections between the test fixture and the transformer have been made properly. This is particularly important when Kelvin connections are required, perhaps for a test to follow, as a resistance measurement will confirm that both the power lead and sense lead are making good electrical contact. To check that the resistance of a winding is correct, the tester applies a constant current (dc) to the selected winding. Both the current through and the voltage across the winding are measured; dividing the voltage by the current gives the value of the resistance.
Specifying the Test Limits

Maximum Value - Specify limit as tightly as possible to ensure that correct wire has been used.

Minimum Value - Not usually so critical - can be set to any value that ensures that there is no solder splash causing a short circuit between pins.
2.3 RLS or RLP - Equivalent Series or Parallel Resistance

Where Used
The equivalent series or parallel resistance measurements are alternatives to a Q factor measurement to follow the inductance test in the program. As with the Q factor measurement, an equivalent series or parallel resistance test would normally be used for signal, pulse and switched mode power transformers, where the normal operating conditions require only small excursions of the B-H curve, never extending beyond the linear regions. An equivalent resistance test is also one way of highlighting shorted turns within the transformer.

Measurement Conditions
As with measuring inductance and Q factor, to measure an equivalent series or parallel resistance, the tester applies an AC voltage across the selected winding. It then measures the voltage across and current through the winding using harmonic analysis. The measured voltage is divided by the current to obtain a complex impedance and the equivalent series or parallel resistance calculated.

If, in the program, the RLS or RLP test follows either an LS or LP test which has the same test conditions (voltage and frequency), and is applied to the same winding, then the measurement results from the previous inductance test can be re-used, saving program execution time.

The test signal can have a frequency in the range 20Hz to 3 MHz, and an amplitude from 1 mV to 5 V. Normally when following an inductance test, you would choose the same test conditions for the RLS or RLP test. If the RLS or RLP test does not have an associated inductance test, then choose the test conditions as detailed in under section 1.11, based on the value of the inductance of the winding under test.
2.4 LS or LP - Primary Inductance (Series or Parallel)

An ideal transformer, with the secondaries open-circuit, presents an infinite impedance to an AC voltage applied to the primary, the transformer acts as though it were an infinite inductor.

In practice the transformer presents a finite inductive impedance to the applied voltage given by:

\[ \text{Inductive impedance} \ (X_L) = 2\pi f L \ (\text{ohms}) \]

Where \( L \) is the inductance of the core (Henry’s) and \( f \) is the frequency of the applied voltage.

The primary inductance is therefore a measure of the input impedance of the transformer. From this equation, it can be seen that the smaller the inductance, the larger will be the current that will flow when the transformer is energized.
**Measurement Conditions**

To measure inductance, the tester applies an ac voltage across the selected winding; it then measures the voltage across and the current through the winding using harmonic analysis. The measured voltage is divided by the current to obtain a complex impedance and the inductance is calculated.

The test signal can have a frequency in the range 20 Hz to 3 MHz, and an amplitude from 1 mV to 5 V.

Generally, it is not necessary to measure the inductance at the normal operating conditions of the transformer, which could involve, for example, voltage levels of hundreds of volts. This is because the B-H curve can normally be assumed to be linear in the operating region, and the inductance measured at a low level represents the inductance that will appear in use.

Also, it can usually be assumed that the inductance value does not vary significantly with frequency. Therefore, although high frequencies are available with the tester, measurement frequencies above a few hundred kilohertz should be used with caution. This is because the errors caused by the stray inductance and capacitance of your fixture may become much more significant at these frequencies. Compensation can be used to eliminate these errors.

The following table suggests suitable test conditions for different values of expected primary inductance:

<table>
<thead>
<tr>
<th>Inductance Range</th>
<th>Preferred test signal</th>
<th>Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100nH → 1uH</td>
<td>300KHz</td>
<td>10mV</td>
<td></td>
</tr>
<tr>
<td>1uH → 10uH</td>
<td>100KHz</td>
<td>30mV</td>
<td></td>
</tr>
<tr>
<td>10uH → 100uH</td>
<td>30KHz</td>
<td>50mV</td>
<td></td>
</tr>
<tr>
<td>100uH → 1mH</td>
<td>10KHz</td>
<td>100mV</td>
<td></td>
</tr>
<tr>
<td>1mH → 10mH</td>
<td>1KHz</td>
<td>100mV</td>
<td></td>
</tr>
<tr>
<td>10mH → 100mH</td>
<td>100Hz</td>
<td>100mV</td>
<td></td>
</tr>
<tr>
<td>100mH → 1H</td>
<td>100Hz</td>
<td>300mV</td>
<td></td>
</tr>
<tr>
<td>1H → 10H</td>
<td>50Hz</td>
<td>1V</td>
<td></td>
</tr>
<tr>
<td>10H → 100H</td>
<td>50Hz</td>
<td>5V</td>
<td></td>
</tr>
<tr>
<td>100H → 1KHz</td>
<td>50Hz</td>
<td>5V</td>
<td></td>
</tr>
<tr>
<td>1KHz → 10KHz</td>
<td>20Hz</td>
<td>5V</td>
<td></td>
</tr>
</tbody>
</table>
The Test Conditions for Inductance Measurement

Wherever possible, this table should be used for all inductance tests. The inductance range should be chosen based on minimum value of inductance expected. When choosing the test conditions, the following potential problems should be considered:

a) Current levels
The upper voltage limits should be chosen to give a maximum current level of about 50mA rms. for the lowest inductance expected. In some cases, this current may cause core saturation, and a lower voltage should be used. The minimum voltage level must be chosen so that the test current does not become so low that it cannot be sensibly measured. The lower voltage limits in the table above always give test currents higher than 3µA rms.

b) Self-Resonant Frequency
At lower frequencies, the capacitance of the windings can normally be ignored because its impedance is much higher than that of the inductance. However, at very high frequencies, this is not so, the capacitance dominates and inductance cannot be measured. The self-resonant frequency of the transformer is the change-over point between these two regions. Normally to get a good measurement of inductance, the test frequency should be less than 20% of the resonant frequency of the transformer. In general, high values of inductance will have a high inter-turn capacitance and hence a low resonant frequency. Where there is a choice of test frequencies always use the lower value, to minimise any problems due to self-resonance.

c) Non-linear inductance
Normally inductance measurements should be used for transformers where the B-H characteristics are linear. However, if inductance measurements are attempted for instance with line frequency transformers where the core material is non-linear even at low signal levels, the measured results can be highly dependent on the applied test signal. This can be a problem when trying to compare measurements made on commercially available impedance bridges, or component testers, with measurements made using the AT5600. The test signal in such bridges is usually determined within the instrument, and is often at a fixed frequency and at a voltage level, which is not guaranteed to be constant for all value of inductance. Usually, if the actual test conditions of the bridge can be determined, and the tester is then programmed to deliver the same test conditions across the inductance the results will then agree. (See also the comments below on differences caused by the choice of equivalent circuit)

d) Equivalent circuit
Inductance is always measured as part of a complex impedance; the result being expressed in terms of either a series or parallel equivalent circuit. Note that, for any given winding, the inductance values for the two circuits are not necessarily the same. This should be born in mind when specifying the test limits.
2.5 LSB or LPB - Inductance with Bias Current (Series or Parallel)

Where Used
With the LSB and LPB tests, the AT5600 offers two further ways to confirm that the transformer has been assembled properly, with the appropriate number of turns, the right grade of magnetic material for the core, and the correct air gap if required. These tests would normally be used for transformers designed to be used in applications where a large dc current is flowing through one or more of the windings.

Measurement Conditions
To measure inductance with bias, the tester firstly applies the programmed bias current to the winding under test. When this has stabilised, it then applies an ac voltage across the selected winding, and measures the voltage across and the current through the winding using harmonic analysis. The measured voltage is divided by the harmonic current to obtain a complex impedance and the inductance is calculated.

The bias current can be programmed in the range 10 mA to 400 mA. The (ac) test signal can have a frequency between 20Hz and 3 MHz, and an amplitude from 1 mV to 5 V.

Usually, the signal frequency and voltage are chosen so that, with the expected inductance, the resulting signal current is less than 20% of the bias current.

Recommended test signals generally would be the same as given in section 1.11 for the normal inductance test. However, if the recommended levels correspond to too high a signal current, then use a corresponding smaller test voltage.

It is not normally recommended that the test frequency be increased in an attempt to reduce the signal current, as this may lead to other problems, such as those caused by parasitic inductance and capacitance of the test fixture, and the self-resonant frequency of the transformer itself.
2.6 QL - Q factor

When a transformer is energized the changing magnetic field in the core causes losses in the core.
Two types of losses occur in the core: - Hysteresis losses and Eddy current losses. These losses are described in section 1.3 and 1.4

The total of these losses can be represented on the transformer equivalent circuit by a resistance associated with the inductance of the winding. This resistance may be shown either in series with an inductance or in parallel with an inductance, as shown in the following diagrams:

Series Equivalent cct.       Parallel Equivalent cct.

![Series Equivalent Circuit](image1)
![Parallel Equivalent Circuit](image2)

Either the parallel or series circuit can be used, with equal validity, in the transformer equivalent circuit where:

\[ R_p = \left( R_s^2 + \omega^2 L_s^2 \right) / R_s \quad \omega = 2\pi f \]

\[ L_p = \left( R_s^2 + \omega^2 L_s^2 \right) / \omega^2 L_s \]
It is clear from this equation that series and parallel inductance do not necessarily have the same value, so when a value for inductance is specified, it must be specified as series or parallel equivalent circuit. For a series circuit, the 'quality factor' Q is defined as:

\[ Q = \frac{\omega L_s}{R_s} \]

For a given inductance, the lower the value of the equivalent series resistance, the higher is the value of Q, i.e. the 'better' the coil. Typical value of Q ranges from about 2 to several hundred.

**Where Used**
The Q factor measurement would normally follow a measurement of the inductance of the primary winding in the test program. As with an inductance measurement, the Q factor test would normally be used for signal, pulse and switched mode power transformers, where the normal operating conditions require only small excursions of the B-H curve, never extending beyond the linear regions.

A Q factor test is one way of highlighting shorted turns within the transformer.

**Measurement Conditions**
To measure Q factor, the tester performs exactly the same steps that would be used to measure inductance. The only difference is in the calculation at the end of the test: the measured voltage is divided by the current to obtain a complex impedance from which the Q factor is calculated.

The test signal can have a frequency in the range 20Hz to 3 MHz, and an amplitude from 1 mV to 5 V.

Normally when following an inductance test, you would choose the same test conditions for the QL test. If the QL test does not have an associated inductance test, then choose the test conditions as detailed in the Table on page 23, based on the value of the inductance of the winding under test.
2.7 D – Dissipation Factor or Tanδ

The parameter ‘D’ is most often used as a measurement of the losses in a capacitor. It is analogous to Q for a transformer winding. For this equivalent circuit the Dissipation Factor D is defined as:

\[ D = \frac{R_s}{1/\omega C_s} \] (where \( \omega = 2\pi f \))

For a given capacitance, the lower the equivalent series resistance, the lower is the value of the dissipation factor or tanδ, i.e. the ‘better’ the capacitor.

**Where used**
The dissipation factor test would normally be used for capacitors of all types. A D factor test will help to determine that the capacitor has been manufactured correctly.

**Measurement conditions**
To measure Dissipation Factor, the tester applies an ac voltage across the selected winding, and measures the voltage across and the current through the winding. Using harmonic analysis, the measured voltage is divided by the current to obtain a complex impedance from which the Dissipation Factor is obtained.

**Choosing the test signal**
For optimum accuracy and performance, use the test conditions chosen for capacitance in a later section of this chapter.
2.8 LL - Leakage Inductance

If a secondary winding of an ideal transformer is short circuited, the transformer would present zero impedance to the supply, and an infinite current would flow.

In practice the actual current is not infinite, even if there are no winding resistances, because it is limited by the fact that the coupling between windings is not perfect: -
As a result of imperfect coupling, a short-circuited transformer acts as if there was an inductive impedance in series with a winding:

![Diagram of an ideal transformer with an inductive impedance (L1) in series with a winding.](image)

This impedance is known as the leakage inductance, and is a measure of the coupling between windings. Low leakage inductance implies good coupling; high leakage inductance poor coupling.

Leakage inductance limits the flow of current when the transformer is short circuited. Like winding resistance, it also causes the output voltage to fall with increasing load current, adding to the transformer regulation. In SMPS transformers, leakage inductance causes transistor overvoltage when the transistor is turned off. Most transformer designs require low leakage inductance but for some designs (e.g. for electronic ballasts, constant voltage transformers and resonant converter transformers), leakage inductance is deliberately introduced as part of the overall circuit design.

Leakage inductance can be reduced by ensuring that windings are in close physical proximity to each other, have long winding lengths or are interleaved.
Low leakage designs:

- a) Close proximity
- b) Toroid - long
- c) Interleaved winding length

Leakage inductance can be increased by separating windings, providing short winding lengths or introducing alternate flux paths.

High leakage designs:

- a) Short winding lengths
- b) Increase separation between winding
- c) Alternate flux path
**Where Used**
Leakage inductance is important in many applications. One example is fly back designs for high frequency switched mode power supplies, where the leakage inductance must be less than a specified critical value for proper operation.

**Measurement Conditions**
Leakage inductance is tested by measuring the inductance of a 'primary' winding when one or more 'secondary' windings are shorted out. In performing the calculation at the end of the test to extract the inductance value from the measured winding impedance, the tester uses a series equivalent circuit.

In making the measurement, the tester automatically compensates for the impedance of the wiring, the connections and the relays in the shorting path.

Leakage inductance can be measured using a test current in the range 20µA to 100 mA at a frequency of 20Hz to 3 MHz. You may choose a suitable test current and frequency based on the expected value of the leakage inductance using the following table:

<table>
<thead>
<tr>
<th>Leakage Inductance range</th>
<th>Preferred test signal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
</tr>
<tr>
<td>100nH</td>
<td>300kHz</td>
</tr>
<tr>
<td>1uH</td>
<td>100kHz</td>
</tr>
<tr>
<td>10uH</td>
<td>30kHz</td>
</tr>
<tr>
<td>100uH</td>
<td>10kHz</td>
</tr>
<tr>
<td>1mH</td>
<td>1kHz</td>
</tr>
<tr>
<td>10mH</td>
<td>100Hz</td>
</tr>
<tr>
<td>100mH</td>
<td>100Hz</td>
</tr>
<tr>
<td>1H</td>
<td>50Hz</td>
</tr>
</tbody>
</table>
NOTE: Because leakage inductance is measured with a secondary winding shorted out, be careful to choose a test signal that will not cause excessive currents to flow. This is particularly significant in transformers where the turns ratio is very high and the shorted winding has only a few turns. If, for example, the primary winding has 300 turns, and the secondary 3 turns, a test current of 10 mA flowing through the leakage inductance on the primary side will give rise to a current of 1 Amp flowing in the shorted secondary winding.

In order to protect transformer windings, the test current when measuring leakage inductance is limited in the table to 50 mA maximum. In addition, the problem of self-resonant frequency listed under the primary inductance test also applies when measuring leakage inductance, so always use the lower of the available band of frequencies.
2.9 C - Inter-Winding Capacitance

Practical transformers, with windings in proximity to each other, exhibit capacitance between those windings, the inter-winding capacitance.

The value of capacitance depends on factors such as the layout and the thickness of the insulation tape.

For applications, such as communication transformers the interwinding capacitance has to be carefully controlled to guarantee the transformer frequency response. In SMPS transformers the interwinding capacitance can transmit common mode noise between windings.
Where Used
Capacitance occurs in transformers due to the physical proximity of, and electrostatic coupling between, different turns of wire. In general, the capacitance is distributed between the different layers within a winding, and between the outside layer of one winding and the inside layer of the next. Inter-winding capacitance may be of interest in transformers used in audio, medical and instrumentation applications, where isolation between primary and secondary windings is important. It can also play an important part in the circuit operation of switch-mode transformers where, for example, too large a capacitance may give rise to a large amount of noise at the switching frequency being coupled into sensitive circuits connected to the secondary windings.

Measurement Conditions
To measure capacitance, the tester applies an ac voltage between the windings to be tested, usually with all taps on each winding shorted together. It then measures the voltage between the windings, and the resulting current using harmonic analysis. Dividing the voltage by the current gives the inter-winding impedance, from which the capacitance may be calculated. The test voltage can be in the range of 1 mV to 5 V at a frequency of 20Hz to 3 MHz.

The table below gives the recommended test conditions for different values of capacitance:

<table>
<thead>
<tr>
<th>Capacitance range</th>
<th>Preferred test signal</th>
<th>Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1pF</td>
<td>10pF</td>
<td>100KHz</td>
<td>5V</td>
</tr>
<tr>
<td>10pF</td>
<td>100pF</td>
<td>100KHz</td>
<td>5V</td>
</tr>
<tr>
<td>100pF</td>
<td>1nF</td>
<td>10KHz</td>
<td>5V</td>
</tr>
<tr>
<td>1nF</td>
<td>10nF</td>
<td>1KHz</td>
<td>5V</td>
</tr>
<tr>
<td>10nF</td>
<td>100nF</td>
<td>100Hz</td>
<td>5V</td>
</tr>
</tbody>
</table>
The Test Conditions for Capacitance Measurement

When choosing the test conditions, the following potential problems should be considered:

a) Current levels
For larger capacitance, particularly at higher frequencies, the current flowing during the measurement can be very high, and similarly the measured current could also be very small for small capacitance at lower frequencies and voltages. Where possible, you should use the recommended test signal levels in the table above to ensure that the currents which flow can be measured accurately.

b) Non-linear Capacitance
Normally non-linearity’s in the stray capacitance of transformers are not a problem, and therefore capacitance is measured with as large a voltage as possible.

c) Equivalent Circuit
As with inductance, capacitance is actually measured as a complex impedance, and therefore the result can be expressed in terms of either a series or a parallel equivalent circuit.
It was explained in section 1.5 of this chapter that parallel and series equivalent inductance do not necessarily have the same values. The same is true for capacitance; parallel and series equivalents can also be different.
The tester always uses a parallel equivalent circuit for capacitance measurements.
2.10 TR - Turns ratio and phasing

Turns Ratio describes the ratio of the turns between one winding and another.

In the above example:

\[ \text{Turns ratio} = \frac{\text{Secondary Turns}}{\text{Primary Turns}} = \frac{50}{100} = 0.5 \]

In the above 'ideal' transformer, applying 10 V to the primary would produce 5 V on the secondary. In practice the output voltage of an actual transformer will be slightly less than this due to the parasitic elements described in the equivalent circuit. Due to those elements, the ratio measured is usually the 'voltage ratio, not the actual 'turns ratio'.

Phasing

Applying an AC voltage to the primary of the transformer will produce an AC voltage on the secondary.

This secondary voltage may be in-phase with the primary voltage, or it may be in anti-phase depending on the direction of winding and the termination of the windings.

This phasing is represented by the 'dot' associated with each winding.

![Diagram of phasing](image)

a) In Phase  

b) Anti-Phase
For most applications, it is important to know that the windings are phased correctly as well as knowing the turns or voltage ratio.
The AT5600 offer two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns. Turns ratio is the preferred test for signal, pulse and switched mode power transformers, where the normal operating conditions require only small excursions of the B-H curve, never extending beyond the linear regions. (For line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions, the preferred method is to use an open-circuit voltage test to check for the correct numbers of turns on each winding.) Clearly a turns ratio test cannot tell you the actual number of turns on a winding, only the ratio between one winding and the next. You should therefore have at least one inductance test in your program to give confidence that the absolute number of turns is correct as well as the ratio.

Measurement Conditions
To measure turns ratio, a test source voltage is applied to one winding, the energised winding, and the voltages across two other windings (one of which may also be the energised winding) are measured using harmonic analysis. The turns ratio is measured by dividing one measured voltage by the other, and making a compensation for the effects of winding resistance. It is recommended that you choose the winding with the highest number of turns as the one to be energised. A possible exception to this rule is when you wish to measure the ratio between two windings, which should be accurately matched at 1:1. In this case it may be better to energise a third winding with a lower number of turns, to ensure that any measurement errors apply equally to the two windings under test. You can specify the signal to be applied to the energised winding to have a frequency in the range 20Hz to 3 MHz, and an amplitude from 1 mV to 5 V. The recommended test conditions depend on the inductance of the energised winding; they are given in the table below assuming that the energised winding is the one with the highest number of turns:
### Inductance of the Energised Winding

<table>
<thead>
<tr>
<th>Inductance of the Energised Winding</th>
<th>Preferred test signal Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100nH → 1uH</td>
<td>300KHz</td>
<td>10mV</td>
</tr>
<tr>
<td>1uH → 10uH</td>
<td>100KHz</td>
<td>30mV</td>
</tr>
<tr>
<td>10uH → 100uH</td>
<td>30KHz</td>
<td>50mV</td>
</tr>
<tr>
<td>100uH → 1mH</td>
<td>10KHz</td>
<td>100mV</td>
</tr>
<tr>
<td>1mH → 10mH</td>
<td>1KHz</td>
<td>100mV</td>
</tr>
<tr>
<td>10mH → 100mH</td>
<td>100Hz</td>
<td>100mV</td>
</tr>
<tr>
<td>100mH → 1H</td>
<td>100Hz</td>
<td>300mV</td>
</tr>
<tr>
<td>1H → 10H</td>
<td>50Hz</td>
<td>1V</td>
</tr>
<tr>
<td>10H → 100H</td>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>100H → 1KH</td>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>1KH → 10KH</td>
<td>20Hz</td>
<td>5V</td>
</tr>
</tbody>
</table>

### The Test Conditions for Turns Ratio Measurement

Notes: The signal is applied to the primary winding, or the winding, which has the largest number of turns. However, if by doing this, the expected voltage on the winding with the smallest number of turns falls below 1 mV, then the test voltage should be increased. This may also require an increase in the test frequency so that the current taken by the driven winding does not become too large, but in general this frequency increase should be kept as small as possible to avoid problems caused by stray capacitance at high frequencies.

### Where Matching in Groups is Important:

In some transformer designs, the turns ratio between a primary winding and a secondary winding is not as important as the ratio between different primaries or different secondaries. To make the most accurate measurements in such cases apply the test signal to the primary winding and measure the turns-ratio from primary to one of the secondaries. Then, leaving the primary energised as above, measure the turns ratio between the secondaries. Next, energise a secondary winding (possibly at a different voltage and / or frequency depending on its inductance) and measure the turns ratio between the various primaries. In this way windings, which should be matched are treated equally during the test.
Specifying the Test Limits

When specifying turns ratio tests, it is preferable to avoid limits which are unnecessarily tight, and which may therefore lead to measurement difficulties. For example, if two equal secondary windings should have 10 turns each, the ratio should be 1:1. One turn in error would produce a ratio error of 10% or -10% (i.e. 11:10 or 10:11), and therefore limits of +5% and -5% would be suitable to detect the error.
2.11 TRL - Turns Ratio by Inductance

Where Used
The AT5600 offers two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns.

Turns ratio is the preferred test for signal, pulse and switched mode power transformers, where the normal operating conditions require only small excursions of the B-H curve, never extending beyond the linear regions.

Where the magnetic coupling between the primary and secondary is poor, it is preferable to measure the turns ratio by inductance. This test measures the inductance of both the primary and secondary and calculates the turns ratio from these measured values. (For line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions, the preferred method is to use an open-circuit voltage test to check for the correct number of turns on each winding.)

Clearly a turns ratio test cannot tell you the actual number of turns on a winding, only the ratio between one winding and the next. You should therefore have at least one inductance test in your program to give confidence that the absolute number of turns is correct as well as the ratio.

Measurement Conditions
The inductance of a winding can often depend upon the flux density in the core/windings. Since during measurement, the flux density will depend upon the signal energising the winding, it is important that both windings are energized at the same level. This will ensure that both inductances are measured along the same region of the B/H curve of the core, to give a true ratio.

Setting the Test Parameters
The simplest method of setting the test parameters is to use the ‘Measure’ button, to do this you have to program the test from a computer which is connected to the Auxiliary port of the tester. There are two other methods of inputting the test parameters, one is to set the primary voltage and frequency and let the editor set the secondary voltage, and the second is to set both voltages manually.

Using the Measure Button to Set Test Parameters
To do this you must be programming the test from a computer that is connected to the tester’s auxiliary port. Select the integration period you require, enter the primary and secondary terminals, then click on the measure button. The editor will then enter the test signal and show the measured turns ratio. Set percentage limits on this ratio and click ‘OK’ (you may select a polarity test before clicking ‘OK’).
Using the Auto Button to Set Secondary Voltage
To do this you must know the primary inductance.
Select the test voltage and frequency for the primary from the table below and enter them in the TRL dialogue box. Enter the turns ratio, then press the ‘Auto’ button next to the secondary voltage parameter, the tester will automatically select the appropriate test voltage for the secondary winding when the program is running.

Setting the Primary and Secondary Parameters Manually
To do this you will need to know the inductance of the primary and secondary windings.
The optimum test conditions are chosen for an inductance value that is between the primary and secondary \( L_m \).
Look up the recommended test signal for this inductance.
Enter the recommended frequency for this inductance as the test frequency.
The primary and secondary voltages can be calculated from the following:

\[
L_m = \sqrt{L_p \times L_s}
\]

\[
V_s = V_m \sqrt{\frac{N_s}{N_p}} \quad V_p = V_m \sqrt{\frac{N_p}{N_s}}
\]

Where:
- \( L_m \) = Intermediate inductance
- \( L_p \) = Primary inductance
- \( L_s \) = Secondary inductance
- \( V_p \) = Primary voltage
- \( V_s \) = Secondary voltage
- \( V_m \) = Intermediate voltage
- \( N_p \) = Primary turns
- \( N_s \) = Secondary turns
### Intermediate Inductance ($L_m$) vs. Preferred test signal

<table>
<thead>
<tr>
<th>Intermediate Inductance ($L_m$)</th>
<th>Preferred test signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100\text{nH}$</td>
<td>$1\text{uH}$</td>
</tr>
<tr>
<td>$1\text{uH}$</td>
<td>$10\text{uH}$</td>
</tr>
<tr>
<td>$10\text{uH}$</td>
<td>$100\text{uH}$</td>
</tr>
<tr>
<td>$100\text{uH}$</td>
<td>$1\text{mH}$</td>
</tr>
<tr>
<td>$1\text{mH}$</td>
<td>$10\text{mH}$</td>
</tr>
<tr>
<td>$10\text{mH}$</td>
<td>$100\text{mH}$</td>
</tr>
<tr>
<td>$100\text{mH}$</td>
<td>$1\text{H}$</td>
</tr>
<tr>
<td>$1\text{H}$</td>
<td>$10\text{H}$</td>
</tr>
<tr>
<td>$10\text{H}$</td>
<td>$100\text{H}$</td>
</tr>
<tr>
<td>$100\text{H}$</td>
<td>$1\text{KH}$</td>
</tr>
<tr>
<td>$1\text{KH}$</td>
<td>$10\text{KH}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Voltage ($V_m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300KHz</td>
<td>10mV</td>
</tr>
<tr>
<td>100KHz</td>
<td>30mV</td>
</tr>
<tr>
<td>30KHz</td>
<td>50mV</td>
</tr>
<tr>
<td>10KHz</td>
<td>100mV</td>
</tr>
<tr>
<td>1KHz</td>
<td>100mV</td>
</tr>
<tr>
<td>100Hz</td>
<td>100mV</td>
</tr>
<tr>
<td>300mV</td>
<td>1V</td>
</tr>
<tr>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>20Hz</td>
<td>5V</td>
</tr>
</tbody>
</table>

### The Test Conditions for Turns Ratio by Inductance Measurement

**Specifying the Test Limits**

When specifying turns ratio tests, it is preferable to avoid limits which are unnecessarily tight, and which may therefore lead to measurement difficulties.

For example, if two equal secondary windings should have 10 turns each, the ratio should be 1:1. One turn in error would produce a ratio error of 10% or -10% (i.e. 11:10 or 10:11), and therefore limits of +5% and -5% would be suitable to detect the error.
2.12 Z, ZB – Impedance, Impedance with Bias

Where Used
The impedance test measures the impedance of a transformer winding by applying a specified voltage and frequency and by measuring the current that flows, calculating the magnitude of the complex impedance.

Measurement Conditions

![Diagram of impedance measurement](image.png)

The load resistor is assumed to be on the fixture, but not shown on the Editor schematic. It is switched in circuit using an OUT test that must be inserted in the program before the Z test. (The relay patterns associated with inserting and removing fixture resistors have deliberately not been included in the Z test dialogue for two reasons: a) it would make the dialogue too complicated, and b) it is not always necessary - e.g. in the case of a fixture where the resistor is permanently fitted in circuit).

The test voltage is applied to the input winding, and the voltage and current measured. From the measured results the impedance is calculated.
2.13 R2 – DC Resistance Match

Where Used
The DC resistance match test – as opposed to an ordinary DC resistance measurement (R) - is used on audio and telecommunications transformers, where it is important that the resistance of different pairs of windings is controlled and matched to a specified ratio. The absolute value of the resistances may be of less importance to the performance of the transformer than the match between two resistances.

Measurement Conditions
To measure DC resistance match, the tester makes two DC resistance measurements (see the R test) and compares the two results. Limits for the match of the two measured resistances may be set in terms of the ratio between them (e.g. 1:1 ± 5%). By adding further DC resistance match tests to the test program, any number of DC resistances can be tested for match.
2.14 L2 – Inductance Match

Where Used
The inductance match test calculates the ratio between two inductances on two windings. An equivalent series inductance measurement is performed on each winding by measuring the complex impedance. This test is suitable for switched mode power supply transformers, and audio & telecommunication transformers. It checks matching between windings.

Measurement Conditions
When calculating the inductance match, the tester performs two inductance measurements. Firstly, the unit applies an AC voltage across the first winding; it then measures the voltage across and the current through the winding using harmonic analysis. The measured voltage is divided by the current to obtain a complex impedance and the inductance is calculated. This is then repeated for the second winding. The inductance match is the ratio of first to second winding inductance. The test signal can have a frequency in the range 20Hz to 3 MHz, and an amplitude from 1 mV to 5 V.

Generally, it is not necessary to measure the inductance at the normal operating conditions of the transformer, which could involve, for example, voltage levels of hundreds of volts. This is because the B-H curve can normally be assumed to be linear in the operating region, and the inductance measured at a low level represents the inductance that will appear in use. Also, it can usually be assumed that the inductance value does not vary significantly with frequency. Therefore, although high frequencies are available with the tester, measurement frequencies above a few hundred kilohertz should be used with caution. This is because the errors caused by the stray inductance and capacitance of your fixture may become much more significant at these frequencies. Compensation can be used to eliminate these errors.
The following table suggests suitable test conditions for different values of expected average inductance:

<table>
<thead>
<tr>
<th>Average Inductance (Geometric Mean)</th>
<th>Preferred test signal Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100nH</td>
<td>1uH</td>
<td>300KHz</td>
</tr>
<tr>
<td>1uH</td>
<td>10uH</td>
<td>100KHz</td>
</tr>
<tr>
<td>10uH</td>
<td>100uH</td>
<td>30KHz</td>
</tr>
<tr>
<td>100uH</td>
<td>1mH</td>
<td>10KHz</td>
</tr>
<tr>
<td>1mH</td>
<td>10mH</td>
<td>1KHz</td>
</tr>
<tr>
<td>10mH</td>
<td>100mH</td>
<td>100Hz</td>
</tr>
<tr>
<td>100mH</td>
<td>1H</td>
<td>100Hz</td>
</tr>
<tr>
<td>1H</td>
<td>10H</td>
<td>50Hz</td>
</tr>
<tr>
<td>10H</td>
<td>100H</td>
<td>50Hz</td>
</tr>
<tr>
<td>100H</td>
<td>1KH</td>
<td>50Hz</td>
</tr>
<tr>
<td>1KH</td>
<td>10KH</td>
<td>20Hz</td>
</tr>
</tbody>
</table>

Test Conditions for Inductance Match Measurement

Wherever possible, this table should be used for all inductance tests. The inductance range should be chosen based on minimum value of inductance expected.

When choosing the test conditions, the following potential problems should be considered:

a) Current levels
The upper voltage limits should be chosen to give a maximum current level of about 100 mA rms. for the lowest inductance expected. In some cases, this current may cause core saturation, and a lower voltage should be used. The minimum voltage level must be chosen so that the test current does not become so low that it cannot be sensibly measured. The lower voltage limits in the table above always give test currents higher than 3 µA rms.

b) Self-Resonant Frequency
At lower frequencies, the capacitance of the windings can normally be ignored because its impedance is much higher than that of the inductance. However, at very high frequencies, this is not so, the capacitance dominates and inductance cannot be measured. The self-resonant frequency of the transformer is the change-over point between these two regions. Normally to get a good measurement of inductance, the test frequency should be less than 20% of the resonant frequency of the transformer.
In general, high values of inductance will have a high inter-turn capacitance and hence a low resonant frequency. Where there is a choice of test frequencies always use the lower value, to minimise any problems due to self-resonance.

c) Non-linear inductance
Normally inductance measurements should be used for transformers where the B-H characteristics are linear. However, if inductance measurements are attempted for instance with line frequency transformers where the core material is non-linear even at low signal levels, the measured results can be highly dependent on the applied test signal. This can be a problem when trying to compare measurements made on commercially available impedance bridges, or component testers, with measurements made using the AT Series testers. The test signal in such bridges is usually determined within the instrument, and is often at a fixed frequency and at a voltage level, which is not guaranteed to be constant for all value of inductance. Usually, if the actual test conditions of the bridge can be determined, and the tester is then programmed to deliver the same test conditions across the inductance the results will then agree. (See also the comments below on differences caused by the choice of equivalent circuit).

d) Equivalent circuit
Inductance is always measured as part of a complex impedance; the result being expressed in terms of either a series or parallel equivalent circuit. Note that, for any given winding, the inductance values for two circuits are not necessarily the same; this should be born in mind when specifying the test limits.
2.15 C2 – Capacitance Match

Where Used
The inter-winding capacitance match test calculates the ratio between two capacitance measurements on two groups of windings. It is measured by applying a specified ac voltage between two separate windings and the voltage across and current flow between the two windings is measured to obtain a complex impedance. This is performed to the two groups in turn. This test is suitable for switched mode power supply, audio and telecommunication transformers. It checks that the windings are installed in the correct positions on the bobbin.

Measurement Conditions
When calculating capacitance match the tester performs 2 capacitance measurements. Firstly, the tester applies an ac voltage between first group of windings to be tested, usually with all taps on each winding shorted together. It then measures the voltage between the windings, and the resulting current using harmonic analysis. Dividing the voltage by the current gives the inter-winding impedance, from which the capacitance may be calculated. This is then repeated for the second winding group. The capacitance match is the ratio of first to second winding group capacitances. The test voltage can be in the range of 1mV to 5V at a frequency of 20Hz to 3MHz.

The table below gives the recommended test conditions for different values of average capacitance:

<table>
<thead>
<tr>
<th>Average Capacitance (Geometric Mean)</th>
<th>Preferred test signal Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1pF → 10pF</td>
<td>100KHz</td>
<td>5V</td>
</tr>
<tr>
<td>10pF → 100pF</td>
<td>100KHz</td>
<td>5V</td>
</tr>
<tr>
<td>100pF → 1nF</td>
<td>10KHz</td>
<td>5V</td>
</tr>
<tr>
<td>1nF → 10nF</td>
<td>1KHz</td>
<td>5V</td>
</tr>
<tr>
<td>10nF → 100nF</td>
<td>100Hz</td>
<td>5V</td>
</tr>
</tbody>
</table>
The Test Conditions for Capacitance Match Measurement
When choosing the test conditions, the following potential problems should be considered:

a) Current levels
For larger capacitances, particularly at higher frequencies, the current flowing during the measurement can be very high, and similarly the measured current could also be very small for small capacitances at lower frequencies and voltages.
Where possible, you should use the recommended test signal levels in the table above to ensure that the currents which flow can be measured accurately.

b) Non-linear Capacitance
Normally non-linearities in the stray capacitance of transformers are not a problem, and therefore capacitance is measured with as large a voltage as possible.

c) Equivalent Circuit
As with inductance, capacitance is actually measured as a complex impedance, and therefore the result can be expressed in terms of either a series or a parallel equivalent circuit.
It was explained in section 1.5. of this chapter, that parallel and series equivalent inductance do not necessarily have the same values. The same is true for capacitance; parallel and series equivalents can also be different.
The tester uses a parallel equivalent circuit for capacitance measurements, and does not give you a choice of a series equivalent. Generally, this will present no problems, as on the majority of transformers the difference between the two values is usually negligible, and can be ignored.
2.16 GBAL – General Longitudinal Balance

Where Used
The general longitudinal balance test is intended to measure what is effectively the Common Mode Rejection Ratio of a transformer designed to connect to a balanced line. Two measurements are performed each by applying a voltage to the transformer and measuring the resulting voltage to calculate the CMRR. To overcome the differences of three standard methods of measuring the CMRR the GBAL dialogue box has a separate group of terminals X and Y for the first and second measurements respectively. The preferred method of measurement is the LBAL test for which Voltech provide a separate test specifically for this measurement. This test is suitable for audio & telecommunication transformers and checks the effective common mode rejection ratio of the transformer.

Measurement Conditions and Types
Unfortunately, there are several published specifications for measuring longitudinal balance. These are all different, and potentially give different results for the same transformer. To allow each user the freedom to test to his preferred method, the GBAL test has been configured with the greatest flexibility. It therefore consists of two separate measurements which the user can program, and the result is the ratio between the two expressed in dB.

See AT5600 User manual for more details.
2.17 LBAL – Longitudinal Balance

Where Used
The longitudinal balance test is Voltech's preferred method to measure what is effectively the Common Mode Rejection Ratio of a transformer designed to connect to a balanced line.

Two measurements are performed each by applying a voltage to the transformer and measuring the resulting voltage to calculate the CMRR. This test is suitable for audio & telecommunication transformers and checks the effective common mode rejection ratio of the transformer.

See AT5600 User manual for more details.
2.18 ILOS – Insertion Loss

Where Used
The Insertion loss test measures the output power delivered by a transformer to a load, relative to the maximum power theoretically available. A voltage is applied to the input winding and the input/output voltages are measured to calculate the loss. This test is suitable for audio & telecommunication transformers and checks the effective losses in the transformer when used for its application.

Measurement Conditions

\[
\text{ILOS} = 10 \log \left( \frac{V_i^2 R_L}{4 V_o^2 R_S} \right)
\]

The source and load resistors are assumed to be on the fixture, but are not shown on the Editor schematic. They can be switched in/out of circuit using an OUT test that must be inserted in the program before the ILOS test. (the relay patterns associated with inserting and removing fixture resistors have deliberately not been included in the ILOS test dialogue for two reasons: a) it would make the dialogue too complicated, and b) it is not always necessary - e.g. in the case of a fixture where the resistors are permanently fitted in circuit).

The test voltage is applied to the input winding, and the voltages measured on the input and output windings. From the ratio of input and output voltages, and the resistance values (specified by the user in the test dialogue), the insertion loss is calculated.
2.19 RESP – Frequency Response

Where Used
The frequency response test, RESP, may be used to check that the variation in power loss of a telecommunications or audio transformer over a specified frequency range is less than specified limits.

![Insertion Loss vs Frequency Graph]

Measurement Conditions
The RESP test consists of a number of Insertion Loss (ILOS) tests repeated at different frequencies.

The resistors shown are fitted to the test fixture and should be switched out of circuit when making other measurements such as resistance and inductance. This can be done by fitting relays to the fixture and switching them at appropriate points in the test program using OUT tests.

The first ILOS test is made at a reference frequency that is usually near the middle of the band of frequencies of interest. The result of this test is the 0dB reference level. Further ILOS tests are then carried out at user selected frequencies and the results referred to the reference dB level.

If all the referred ILOS results are at or inside the specified limits, the result of a RESP test is the referred ILOS result that is closest to the limit. If any of the referred ILOS results are outside the specified limits, the RESP result is the referred ILOS result that is furthest away from the limit.
2.20 RLOS – Return Loss

Where Used
The Return loss test measures the impedance mismatch between the transformer and a transmission line of a specified impedance. RLOS is calculated from a measurement of the complex impedance and the specified impedance.

This test is suitable for audio & telecommunication transformers and checks the effective input impedance of the transformer in the application.

Measurement Conditions

\[ RLOS = 20 \log \left( \frac{|Z_R + Z_\ell|}{|Z_R - Z_\ell|} \right) \]

The load resistor is assumed to be on the fixture, but not shown on the Editor schematic.

It is switched in circuit using an OUT test that must be inserted in the program before the RLOS test. (The relay patterns associated with inserting and removing fixture resistors have deliberately not been included in the RLOS test dialogue for two reasons:

a) it would make the dialogue too complicated, and

b) it is not always necessary - e.g. in the case of a fixture where the resistor is permanently fitted in circuit).

The test voltage is applied to the input winding, and the voltage and current measured. From the measured results, and the reference impedance value (specified by the user in the test dialogue), the return loss is calculated.

The impedances used are complex, where:

\[ Z_R = R_R + jX_R \]
\[ Z_\ell = R_\ell + jX_\ell \]
2.21 ANGL – Impedance Phase Angle

Where Used
The impedance phase angle test measures the angle $\varnothing$ of the impedance vector $Z$, as shown in the phasor diagram. It represents the phase difference between the fundamental current flowing through a winding and the fundamental voltage across it.

This test is normally used for audio and telecommunication transformers along with the Z test to check the complex impedance presented to the transformers input and output.

Measurement Conditions
The impedance phase angle test measures the angle $\varnothing$ of the impedance vector $Z$, as shown in the phasor diagram. It represents the phase difference between the fundamental current flowing through a winding and the fundamental voltage across it. This test is normally used for audio and telecommunication transformers along with the Z test to check the complex impedance presented to the transformers input and output.

An AC voltage is applied across the winding under test, the complex impedance is determined from measurement of the test voltage and current flowing.

To set the test voltage or current you will need to know the expected impedance of the winding at the test frequency. You can measure this using the ‘Z’ (Impedance) test.

Select the test voltage or current from the table below; find the correct impedance range for your winding and read off the test voltage or current.
<table>
<thead>
<tr>
<th>Impedance Range</th>
<th>Test Voltage</th>
<th>Test Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1MΩ → 100kΩ</td>
<td>5V</td>
<td>-</td>
</tr>
<tr>
<td>100kΩ → 10kΩ</td>
<td>5V</td>
<td>30μA</td>
</tr>
<tr>
<td>10kΩ → 1kΩ</td>
<td>5V</td>
<td>300μA</td>
</tr>
<tr>
<td>1kΩ → 100Ω</td>
<td>3V</td>
<td>3mA</td>
</tr>
<tr>
<td>100Ω → 10Ω</td>
<td>0.5V</td>
<td>10mA</td>
</tr>
<tr>
<td>10Ω → 1Ω</td>
<td>100mV</td>
<td>50mA</td>
</tr>
<tr>
<td>1Ω → 100mΩ</td>
<td>10mV</td>
<td>50mA</td>
</tr>
<tr>
<td>100mΩ → 10mΩ</td>
<td>1mV</td>
<td>50mA</td>
</tr>
<tr>
<td>10mΩ → 1mΩ</td>
<td>-</td>
<td>50mA</td>
</tr>
</tbody>
</table>
2.22 PHAS – Inter-winding Phase Test

Where Used
This test is useful for most types of transformer, although unusual with line frequency transformers and tests for the phase angle between windings. It is most useful for determining the phase effect of audio and telecommunications transformers when placed in a transmission line.

Measurement Conditions
If you are programming the test from a computer that is connected to the auxiliary port of the tester, you may enter the test conditions in the following way.
Select the test terminals, enter the test frequency, click on the measure button and the editor will select the correct voltage and display the measured phase angle.
You can then use this measured angle as a basis for setting your limits.

If your computer is not connected to the tester, you can choose the test voltage from the following table.
N.B. When selecting your energised winding, check that your transformer does not have a large step-up turns ratio between this winding and any other windings as this may cause high voltages to be present during the test.
Energise the winding with the most turns if this is the case.
<table>
<thead>
<tr>
<th>Impedance of Energised Winding</th>
<th>Test Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1\text{M}\Omega$ → $100\text{k}\Omega$</td>
<td>5V</td>
</tr>
<tr>
<td>$100\text{k}\Omega$ → $10\text{k}\Omega$</td>
<td>5V</td>
</tr>
<tr>
<td>$10\text{k}\Omega$ → $1\text{k}\Omega$</td>
<td>5V</td>
</tr>
<tr>
<td>$1\text{k}\Omega$ → $100\text{\Omega}$</td>
<td>3V</td>
</tr>
<tr>
<td>$100\Omega$ → $10\Omega$</td>
<td>0.5V</td>
</tr>
<tr>
<td>$10\Omega$ → $1\Omega$</td>
<td>100mV</td>
</tr>
<tr>
<td>$1\Omega$ → $100\text{m\Omega}$</td>
<td>10mV</td>
</tr>
<tr>
<td>$100\text{m\Omega}$ → $10\text{m\Omega}$</td>
<td>1mV</td>
</tr>
</tbody>
</table>
2.23 TRIM - Trimming Adjustment

THIS TEST IS NO LONGER AVAILABLE
2.24 OUT – Output To User Port

Where Used
OUT is used where additional switching (other than performed by the nodes of the AT) is required for parts of the test program. The User Port on the tester has associated with it 6 ‘Relay Driver’ outputs. The OUT test allows programming of the User Port relay driver outputs to perform additional relay switching as part of the test program.
An example of this would be an application where a transformer has two separate primary windings. An OUT test could be used to connect them in series, allowing them to be tested as a single primary with twice the working voltage.
A second example is the switching of additional resistors mounted on the test fixture allowing tests to be included in a program on a transformer with a loaded secondary winding.

Specifying Test Conditions

Relay Driver Outputs
Each of the relay driver outputs (numbered 0 – 5) is an open collector output which can be set to On or Off as desired:
On = Connected to Gnd (0V)
Off = Open circuit (Floating)

Note:
The relay drivers are set as and when the tester encounters an OUT test.
The settings given will latch until another OUT test is encountered.
Therefore, if the settings are required for one part of the test program only, 2 OUT tests will be required, 1 to turn the appropriate relay drivers on and 1 to turn them back off.

12 Volt Supply Pin
The user port also provides a 12 V output to supply the power to the relays on your test fixture.
2.25 IR - Insulation Resistance

Transformer windings are often insulated from each other and from the core by insulating tape, enamel on the wire or by plastic moulding on the bobbin.
The 'quality' of the insulation can be assessed by applying a DC voltage across the insulation and measuring the value of resistance.
The voltage applied is usually greater than the voltage that the insulation will see in normal use.
Typical test voltage is 200 V to 500 V DC, and the insulation resistance expected will be of the order of one hundred to several thousand MOhms.

Where Used
An Insulation Resistance check is recommended as good practice for most transformers to check the integrity of the insulation between separate windings, or between a winding and a screen.
It is used where winding isolation is a part of the functionality of the transformer, but not part of a safety requirement, for which a Hi-Pot (EHT) test is preferred.
It would therefore be used, for example, between two primary windings, or between two secondary windings.
**Measurement Conditions**

To measure insulation resistance, the tester applies a dc voltage between two groups of windings, with the windings in each group being shorted together.

Each group may contain as many windings as you wish.

The voltage and current are measured; dividing the voltage by the current gives the insulation resistance.

You can also command the tester to perform a compensation measurement on the empty fixture at the start of a test run.

This is recommended as it will allow the tester to subtract the errors due to the fixture from subsequent measurements, to give more accurate results.

The test voltage may be chosen in the range from 100 V to 7 kV

Normally however, you would perform the test with a voltage just greater than twice the highest possible peak working voltage on the winding.

Therefore, for example, to check the isolation between the two primary windings of a line frequency transformer, which could be connected in series and operated at 240V, 800 V would be a suitable test signal.
2.26 HPDC – DC HI-POT

Where Used
Hi-Pot or EHT testing (to check for insulation breakdown between windings or between windings and the screen or core) is often specified for power line transformers or for switched mode power transformers in applications where safety is important.

It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement

During the test, a dc voltage is applied across two groups of windings with the windings in each group being shorted together. The voltage and current are monitored throughout the dwell time; if either the test voltage cannot be maintained, or the current is too large, then a failure will be recorded.

In programming the tester, you may select the voltage (from 100 V to 7 KV DC), the current trip level (1μA to 1 mA), and the ramp up and dwell times, all to suit the specification of the transformer under test.

Many transformer specifications require Hi-Pot testing to be carried out with a dwell time of 60 seconds. Although the transformer must be designed and constructed to meet this, it is common practice to reduce the dwell time for production testing.
2.27 HPAC - AC HI-POT

Where Used
Hi-Pot or EHT testing (to check for insulation breakdown between windings or between windings and the screen or core) is often specified for power line transformers or for switched mode power transformers in applications where safety is important. It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement
During the test, an ac voltage is applied across two groups of windings with the windings in each group being shorted together. The voltage and current are monitored throughout the dwell time; if either the test voltage cannot be maintained, or the current is too large, then a failure will be recorded. In programming the AT5600 you may select the voltage (from 100V to 5kVrms), the frequency (50Hz / 60Hz at the full voltage, or up to 1 kHz at reduced voltage), the current trip level (300μA to 30 mA peak), and the ramp up and dwell times, all to suit the specification of the transformer under test.

Many transformer specifications require Hi-Pot testing to be carried out with a dwell time of 60 seconds. Although the transformer must be designed and constructed to meet this, it is common practice to reduce the dwell time for production testing. During a Hi-Pot test, the Wattage is continuously monitored and adjusted to provide the correct output. If the programmed output voltage cannot be maintained, the tester will automatically display ‘FAIL’, illuminate the red indicator, return a ‘FAIL’ to the server (if used) and sound a warning buzzer (if enabled).
2.28 SURG - Surge Stress Test

Where Used
This test may be used to highlight a short-circuit between adjacent turns in a winding. It is applicable to any transformer, but is particularly suitable for transformers with a large number of turns using very fine wire. For such wire, the enamel coating is very thin, and there is a danger that it will be scratched, giving rise to exposed copper. In some cases, the scratch does not immediately cause a shorted turn, but will leave a weak spot which may eventually fail. By applying a higher than normal voltage across the winding, any weakness in wire insulation will be encouraged to fail.

Measurement Method
Each SURG test can be programmed to consist of a number of impulses. For each impulse, the AT5600 will charge an internal capacitor to the high voltage specified. This stored charge will then be suddenly discharged into the winding-under-test, and the resulting transient voltage will be analysed. The product from the discharge will be a sinusoidal wave with decaying amplitude.

\[
\text{Voltage} \quad V_P = \text{The peak voltage just after switch-on}
\]

At the start of the surge test, the AT5600 performs an initial run to compensate for the effect of the capacitance of the transformer winding. Without this compensation, the peak voltage would be reduced by charge sharing between the winding capacitance and the reservoir capacitance within the AT5600, and would not be the value you require.
Therefore, the full test sequence is as follows:

Preliminary Impulse: The value of $V_P$ is measured, and the starting conditions changed to compensate for the charge sharing effects. If it is as specified for the test, this becomes the first impulse of the sequence, and the transient is analysed. (If not, it is treated as a second preliminary impulse, and impulse #1 is repeated.)

Repeated impulses, up to the number programmed for the test.

Impulse #n: The value of $V_P$ is re-checked, and the transient analysed on each impulse of the sequence.

**Transient Analysis**

During the decay phase after the impulse has been fired, the AT5600 measures both the voltage amplitude along the transient, and the time of decay.

A good transformer will have a clean and sustained transient, with a long decay period. A transformer with a shorted turn will have a heavily damped response, with a shorter decay period.

The calculation performed is to calculate the ‘area’ underneath the graphical plot of the decaying transient. (For the calculation used, both negative peaks and positive peaks add to the total area.)

The area, measured in Volts-seconds, is much smaller for the faulty winding with a shorted turn.

**Specifying the Test Limits.**

It is very difficult to predict the Volts-seconds ‘area’ under the curve from theoretical calculations. The recommended method is to use the Measure Mode to obtain some values.

The procedure is as follows:

Measure the area on a known good transformer; let this result be area $A_G$.

Wrap an additional single turn round the core, short the two ends together, and re-measure the area; let this result be area $A_F$.

Set the limits as follows:

Max Area = $3A_G/2$

Min Area = $(A_G + A_F)/2$

Remember that these limits are taken from only one transformer, and may need to be revised after more have been tested.
2.29 STRW – Stress Watts

When a voltage is applied across a transformer winding, a voltage appears between adjacent turns of the winding. It is essential that the insulation between adjacent turns can withstand this voltage, the inter-turn stress.

This is a particular problem on miniature line frequency transformers, which have a very large number of turns of very fine wire. The enamel coating is very thin, and is easily scratched. Also, such windings consist of many layers and it is easy for wire to drop down the edge of the bobbin and lie adjacent to lower layers, exposing the wire enamel to higher than normal interturn stress voltages.

The problem of inter-turn stress can also occur on high frequency transformers. In this case the number of turns may be small, but the voltage per turn will be very much higher than in a line frequency transformer. Most commonly, the problem of inter-turn stress does not immediately cause a shorted turn but causes a weak spot, which will cause a transformer to fail eventually.

It is one of the most common reasons for transformer failure.
**Where Used**
The Stress Wattage test tests the transformer for breakdown of insulation by measurement of the energising power of a winding, usually the primary, with the remaining windings open circuit. This test applies the voltage, usually twice the normal operating voltage, and continually measures the power to determine any breakdown by changes in the measurement. This test is suitable for sub-miniature line frequency, large line frequency bobbin wound and some HF transformers. It checks the integrity of interturn insulation, the magnetic material and joints.

**Measurement Conditions**
A constant voltage source is applied to the winding under test. Both the rms voltage and the power are measured. If necessary, the voltage can is trimmed to the user specified value, and the measurement repeated. The measurement is repeated many times until the dwell time has elapsed. The result given is the measured power. Usually, the energization is at twice the working voltage and frequency, and has the purpose of trying to create an inter-turn breakdown at a point of potential weakness in the wire enamel. This breakdown is detected by an increase in the measured power.
2.30 MAGI - Magnetizing Current

Magnetizing current is the term used to denote the total current that flows into the primary of a transformer when the transformer is energized at a specific voltage and frequency, with the secondaries open circuited. Although known as magnetizing current it is actually the combination of the current required to magnetize the core ($I_1$) and the current required to supply the losses in the core ($I_2$).

Where Used
The AT5600 offers two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns, the right grade of magnetic material for the core, and the correct air gap if required. Magnetising current and open circuit voltage are the preferred tests for line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions. (For other transformers, such as pulse transformers and those used in switched mode power supplies, inductance and turns ratio are the preferred tests.)
**Measurement Conditions**

When measuring magnetising current, you should normally program the test to apply the highest working voltage at the lowest working frequency to the primary winding.

In the case of a transformer with a split primary, the test can be conducted equally well by energising just one of the primary windings, as opposed to the two in series.

The expected current will be greater for the single winding, rising in proportion to the turns ratio:

\[ I_A = I_{AB} \times \left( \frac{N_{AB}}{N_A} \right) \]

Where

- \( I_A \) = The current to be specified when testing with winding A
- \( I_{AB} \) = The current for windings A and B in series
- \( N_A \) = The number of turns on winding A
- \( N_{AB} \) = The number of turns on A and B in series

(As an alternative, the formula above can be written using the voltage ratio between the two windings, rather than the turns ratio.)

In principle, you may measure the magnetising current using any winding, or any series combination of windings, with the current limit adjusted according to the formula above, because the Ampere-turns required to magnetise a transformer to a given flux level is independent of which winding is used. In practice, the magnetising current waveform may have a transient component following the switch-on of the test voltage. To give you repeatable accurate results, the measurement does not start until any transient has settled.

In addition, to give you the quickest test execution time, the AT5600 uses a switch-on sequence, which minimises such transient effects.

**Specifying the Test Limits**

The AT5600 offers you two ways to specify the test limits:

- Using a true rms measurement
- Using a mean-sense measurement, which is scaled to rms for sinewaves.

Generally, the rms value would be used.

However, you may wish to use the second method if, for example, your test limits have been established by a previous measurement on a low cost multimeter which uses this technique.
2.31 VOC - Open Circuit Voltage

Open circuit voltage is the voltage appearing across a secondary winding when the primary is energized at a specified voltage and frequency, with the secondary at no-load. The voltage is dependent not only on the turns ratio of the transformer, but also on the voltage drop in the primary winding due to the magnetizing current.

Example:

\[
\text{Ideal OC Volts} = 220V \times \frac{100}{1000} = 22.0V \\
\text{Actual OC Volts} = (220 - 15) \times \frac{100}{1000} = 20.5V
\]
**Where Used**
The AT5600 offers two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns.
Open circuit voltage measurements are the preferred tests for line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions.
(For other transformers, such as pulse transformers and those used in switched mode power supplies, a measurement of turns ratio is the preferred test.)
Clearly an open circuit voltage test cannot tell you the actual number of turns on a winding, only the ratio between one winding and the next. You should therefore also include a magnetising current test in your program, to give confidence that the absolute number of turns is correct as well as the ratio.

**Measurement Conditions**
Open circuit voltage is measured by applying an ac test voltage to a selected winding (usually a primary winding), and measuring the resulting voltage produced on another winding.
If, there are several windings to be tested, the program will execute more quickly if the following points are observed:
- Place all the open circuit voltage (VOC) tests consecutively at the same point in the program.
- Use the same energised winding, with the same test voltage and frequency for each test.
- If there is a magnetising current (MAGI) test which has the same energised winding and the same test voltage and frequency, place this immediately before the first open circuit voltage test.

**Specifying the Test Limits**
The AT5600 offers you three ways to specify the test limits:
- Using a normal AC (rms) measurement.
- Using a rectified (mean) measurement.
- Using a DC (mean) measurement.
Generally, the AC (rms) value would be used, but you could use the rectified (mean) or DC (mean) measurements if, for example, you are testing transformers fitted with a rectifying diode.
2.32 WATX - Wattage (External Source)

Where Used
The Wattage test measures the power needed to energise a particular winding, usually the primary, with the remaining windings open circuit. It is usual to configure the test signal to the normal operating conditions of the transformer to determine the power needed to energise the transformer. This test uses an external source to provide the test signal, which must be coupled to the tester via a Voltech AC Source Interface (contact your supplier for details). See the AC Source Interface user manual or the Editor help system for details of how to configure external ac sources for use with an AT5600. This test is suitable for line frequency transformers (25-400 Hz) and checks the no load losses in the transformer.

Measurement Conditions
During the Wattage (External Source) test, a constant, user specified ac voltage from an external source is applied across the winding in question. All other windings are held open circuit during this test. The AT5600 measures the voltage across and current through the winding. The Wattage is the product of the in-phase components of the current and voltage. If, in the program, the WATX test follows either a VOCX or MAGX test which has the same test conditions (voltage and frequency), and is applied to the same winding, then the measurement results from the previous tests can be re-used, saving program execution time.

The test signal can have a frequency in the range 20Hz to 5 KHz, and an amplitude from 5V to 600V depending on the type of external source used. The current rating of a single AC Source Interface is 10 A rms. See also the WATT test which uses the AT5600 internal generator, which can provide up to 270V ac at 25 W.
2.33 STRX – Stress Watts (External Source)

Where Used
The Stress Watts (External Source) test tests the transformer for breakdown of winding insulation by measurement of the energising power of a winding, usually the primary, with the remaining windings open circuit. This test applies the voltage from an external ac source (usually at twice the normal operating voltage and frequency), and measures the power drawn. This test uses an external source to provide the test signal, which must be coupled to the tester via a Voltech AC Source Interface (contact your supplier for details). See the AC Source Interface user manual or the Editor help system for details of how to configure external ac sources for use with an AT5600. This test is suitable for large line frequency bobbin wound and some HF transformers. It checks the integrity of inter-turn insulation, the magnetic material and joints at higher than the normal operating voltage.

Measurements Conditions
A constant voltage (supplied by an external source) is applied to the winding under test. Both the rms voltage and the power are measured. If necessary (and depending on the source type used), the voltage can be trimmed to the user specified value, and the measurement repeated. The measurement is repeated many times until the dwell time has elapsed. The result given is the measured power. The test can detect winding insulation defects in the following way:

The winding insulation is stressed by the use of the increased voltage (increased volts per turn). Increasing the frequency in proportion to the voltage increase ensures that the magnetic core of the transformer is exercised over the same area as it would be at the normal operating voltage and frequency. The core losses remain the same. A significant increase in the power drawn when tested at increased voltage and frequency indicates a failure of the winding insulation that would not be detected at normal operating conditions. The test signal can have a frequency in the range 20Hz to 5 kHz, and an amplitude from 5 V to 600 V depending on the type of external source used. The current rating of a single AC Source Interface is 10 A rms. See also the STRW test which uses the AT5600 internal generator, which can provide up to 270V ac at 25 W.
2.34 MAGX - Magnetizing Current (External Source)

Where Used
The AT5600 offers two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns, the right grade of magnetic material for the core, and the correct air gap if required. Magnetising current and open circuit voltage are the preferred tests for line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions.
(For other transformers, such as pulse transformers and those used in switched mode power supplies, inductance and turns ratio are the preferred tests.)

This version of the MAGI test uses an external source to provide the test signal, which must be coupled to the tester via a Voltech AC Source Interface (contact your supplier for details). See the AC Source Interface user manual or the Editor help system for details of how to configure external ac sources for use with an AT5600.

Measurement Conditions
When measuring magnetising current, you should normally program the test to apply the highest working voltage at the lowest working frequency to the primary winding.
In the case of a transformer with a split primary, the test can be conducted equally well by energising just one of the primary windings, as opposed to the two in series. The expected current will be greater for the single winding, rising in proportion to the turns ratio: -

\[ I_A = I_{AB} \times \frac{N_{AB}}{N_A} \]

Where
- \( I_A \) = The current to be specified when testing with winding A
- \( I_{AB} \) = The current for windings A and B in series
- \( N_A \) = The number of turns on winding A
- \( N_{AB} \) = The number of turns on A and B in series

(As an alternative, the formula above can be written using the voltage ratio between the two windings, rather than the turns ratio.)
In principle, you may measure the magnetising current using any winding, or any series combination of windings, with the current limit adjusted according to the formula above, because the Ampere-turns required to magnetise a transformer to a given flux level is independent of which winding is used.
In practice, the magnetising current waveform may have a transient component following the switch-on of the test voltage. To give repeatable accurate results, the measurement does not start until any transient has settled. The test signal can have a frequency in the range 20Hz to 5 KHz, and an amplitude from 5 V to 600 V depending on the type of external source used. The current rating of a single AC Source Interface is 10 A rms. See also the MAGI test which uses the AT5600 internal generator, which can provide up to 270V ac at 25 W.
2.35 VOCX - O/C Voltage (External Source)

Where Used
The AT5600 offers two basic alternative ways to confirm that the transformer has been assembled properly, with the appropriate number of primary and secondary turns.
Open circuit voltage measurements are the preferred tests for line frequency transformers, designed to operate over the full extent of the B-H curve, including the non-linear regions. (For other transformers, such as pulse transformers and those used in switched mode power supplies, a measurement of turns ratio is the preferred test.)
Clearly an open circuit voltage test cannot tell you the actual number of turns on a winding, only the ratio between one winding and the next. You should therefore also include a magnetising current test (MAGI or MAGX) in your program, to give confidence that the absolute number of turns is correct as well as the ratio.
This version of the VOC test uses an external source to provide the test signal which must be coupled to the tester via a Voltech AC Source Interface (contact your supplier for details). See the AC Source Interface user manual or the Editor help system for details of how to configure external ac sources for use with an AT5600.

Measurement Conditions
Open circuit voltage is measured by applying an ac test voltage (supplied by an external source) to a selected winding (usually a primary winding), and measuring the resulting voltage produced on another winding.
If, there are several windings to be tested, the program will execute more quickly if the following points are observed:
Place all the open circuit voltage (VOCX) tests consecutively at the same point in the program.
Use the same energised winding, with the same test voltage and frequency for each test.
If there is a magnetising current (MAGX) test which has the same energised winding and the same test voltage and frequency, place this immediately before the first open circuit voltage test.
The test signal can have a frequency in the range 20Hz to 5 KHz, and an amplitude from 5 V to 600 V depending on the type of external source used. The current rating of a single AC Source Interface is 10 A rms. See also the MAGI test which uses the AT5600 internal generator, which can provide up to 270V ac at 25 W.

Specifying the Test Limits
The AT5600 offers you three ways to specify the test limits: -Using a normal AC (rms) measurement., Using a rectified (mean) measurement., Using a DC (mean) measurement.
Generally, the AC (rms) value would be used, but you could use the rectified (mean) or DC (mean) measurements if, for example, you are testing transformers fitted with a rectifying diode.
2.36 LVOC – Low Voltage Open Circuit

Where used
The low voltage open circuit test is used to confirm that windings have the correct ratio of turns between them, and that the phasing of the windings is correct. This test is used for signal, pulse and switched mode power transformers where the normal operating conditions require only small excursions of the B-H curve, never extending beyond the linear region. On the AT5600 only, a high voltage open circuit test is available for testing line frequency transformers at their operating point (up to 270V, 1kHz and 2A). See also the test TR – turns ratio.

Measurement conditions
To measure low voltage open circuit, the test signal is applied to one winding called the energized winding. The voltages across another winding (or the same, energized winding) is measured. The low voltage open circuit measurement is the rms value of the voltage measured and can be an ac or a dc voltage.
It is recommended that you choose the winding with the highest number of turns as the one to be energised.
Choosing test conditions

The recommended test conditions depend on the inductance of the energised winding; they are given in the table below assuming that the energised winding is the one with the highest number of turns:

<table>
<thead>
<tr>
<th>Inductance of the Energised Winding</th>
<th>Preferred test signal Frequency</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100nH → 1μH</td>
<td>300kHz</td>
<td>10mV</td>
</tr>
<tr>
<td>1μH → 10μH</td>
<td>100kHz</td>
<td>30mV</td>
</tr>
<tr>
<td>10μH → 100μH</td>
<td>30kHz</td>
<td>50mV</td>
</tr>
<tr>
<td>100μH → 1mH</td>
<td>10kHz</td>
<td>100mV</td>
</tr>
<tr>
<td>1mH → 10mH</td>
<td>1kHz</td>
<td>100mV</td>
</tr>
<tr>
<td>10mH → 100mH</td>
<td>100Hz</td>
<td>300mV</td>
</tr>
<tr>
<td>100mH → 1H</td>
<td>50Hz</td>
<td>1V</td>
</tr>
<tr>
<td>1H → 10H</td>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>10H → 100H</td>
<td>50Hz</td>
<td>5V</td>
</tr>
<tr>
<td>100H → 1kH</td>
<td>20Hz</td>
<td>5V</td>
</tr>
<tr>
<td>1kH → 10kH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.37 ILK - Leakage Current

Leakage current is the current that will flow between the primary windings and secondary windings due to interwinding capacitance. Leakage current is normally specified only for transformers used for medical equipment having patient contact, where it is an additional safety requirement. It is normally measured at normal line voltage and frequency, and typical value of leakage current is tens of microamps.

Where Used
The leakage current test is needed for transformers used in certain applications, mainly medical, where it is an additional safety requirement.

Measurement Conditions
The test is typically carried out by applying the test voltage between all the primary terminals shorted together, and all the secondary terminals and screen shorted together. The voltage and frequency applied are normally the operating voltage and frequency of the transformer.
2.38 LSBX – Inductance with External Bias (Series Circuit)

This test requires the use of one or more Voltech DC1000 Precision DC Bias Current Sources. Contact your Voltech sales office for details.

The inductance of a transformer winding while an external bias current is flowing through it may be tested using series or parallel equivalent circuit models.

Initially the DC bias current is set up and allowed to stabilize.

An AC voltage is applied across the selected winding; the voltage across and current through the winding is then measured using harmonic analysis.

The measured voltage is divided by the current to obtain a complex impedance and the inductance is calculated.
2.39 LPBX – Inductance with External Bias (Parallel Circuit)

This test requires the use of one or more Voltech DC1000 Precision DC Bias Current Sources. Contact your Voltech sales office for details.

The inductance of a transformer winding while an external bias current is flowing through it may be tested using series or parallel equivalent circuit models.

Initially the DC bias current is set up and allowed to stabilize.

An AC voltage is applied across the selected winding; the voltage across and current through the winding are then measured using harmonic analysis.

The measured voltage is divided by the current to obtain a complex impedance and the inductance is calculated.
2.40 ZBX - Impedance with External Bias

This test requires the use of one or more Voltech DC1000 Precision DC Bias Current Sources. Contact your Voltech sales office for details.

The Winding Impedance with External Bias test measures the impedance of a selected winding while applying a DC current from the DC1000 through the winding.

An AC voltage is also applied across the winding from the AT.

This test can be used with inductors to measure the change in impedance with a bias current.
2.41 ACRT - AC HI-POT Ramp

Where Used
Hi-Pot Ramp testing (to check for insulation breakdown between windings or between windings and the screen or core) is often specified for power line transformers or for switched mode power transformers in applications where safety is important. It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement
During the test, an ac target voltage is applied across two groups of windings with the windings in each group being shorted together. The voltage and current are monitored throughout the ramp time.
In programming the AT5600 you may select the voltage (from 100 V to 5.5 kV rms), the frequency (50Hz / 60Hz at the full voltage, or up to 1 kHz at reduced voltage), the current trip level (10μA to 5 mA peak), and the ramp up times (1 to 30 sec), all to suit the specification of the transformer under test.
The purpose is to check the safety isolation between windings, windings and core, or windings and screens, measuring the voltage at which a user specified current is exceeded, by ramping to a maximum user specified voltage at a user specified frequency.

The operation is to ramp up the test voltage while measuring the voltage across the selected terminals and continually monitor the current to check it is below the test limit.
If target voltage is reached before and the maximum monitored current is met the test has "Passed".
If the maximum monitored current is met before the target voltage is reached the test has "Failed".
2.42 DCRT - DC HI-POT Ramp

Where Used
Hi-Pot Ramp testing (to check for insulation breakdown between windings or between windings and the screen or core) is often specified for power line transformers or for switched mode power transformers in applications where safety is important.

It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement
During the test, a dc target voltage is applied across two groups of windings with the windings in each group being shorted together. The voltage and current are monitored throughout the ramp time.

In programming the tester, you may select the voltage (from 100 V to 7 KV dc), the current trip level (1µA to 3 mA), and the ramp up times (1 to 2 sec), all to suit the specification of the transformer under test.

The purpose is to check the safety isolation between windings, windings and core, or windings and screens, measuring the voltage at which a user specified current is exceeded, by ramping to a maximum user specified voltage at a user specified frequency. The operation is to ramp up the test voltage while measuring the voltage across the selected terminals and continually monitor the current to check it is below the test limit.

If target voltage is reached before and the maximum monitored current is met the test has "Passed". If the maximum monitored current is met before the target voltage is reached the test has "Failed".
2.43 ACVB - AC Voltage Break Down

Where Used
This test may be used to check the action of devices such as metal oxide varistors (MOV) that are used to protect transformer windings from transient over-voltages that may be present on the ac supply system. A varistor is a non-linear semiconductor device that has little effect on the circuit until a particular break-down, voltage is reached. When that voltage is reached, the MOV conducts current and limits the applied voltage to its rated break-down voltage. A MOV is limited by the energy (Joules) that it can dissipate under break-down conditions to transient over-voltages only. It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement
During the test, an ac voltage is ramped up across the protection device (MOV) under test and the current is monitored. When the desired current flows, the test stops and the measured result is the break-down voltage. If the voltage is within the desired limits, the test is a PASS. If the voltage is outside the desired limits, or if no breakdown is detected when the maximum voltage is reached, the test is a FAIL. The voltage will ramp to the specified maximum plus 50 V. In programming the AT5600 you may select the voltage (from 100 V to 5 kV rms), the frequency (50Hz / 60Hz at the full voltage, or up to 1 kHz at reduced voltage), the current trip level (10μA to 5 mA peak), and the ramp up times (1 to 30 sec), all to suit the specification n of the transformer under test.
2.44 DCVB - DC Voltage Break Down

Where Used
This test may be used to check the action of devices such as metal oxide varistors (MOV) that are used to protect transformer windings from transient over-voltages that may be present on the ac supply system. A varistor is a non-linear semiconductor device that has little effect on the circuit until a particular break-down, voltage is reached. When that voltage is reached, the MOV conducts current and limits the applied voltage to its rated break-down voltage. A MOV is limited by the energy (Joules) that it can dissipate under break-down conditions to transient over-voltages only. It is typically performed between all primary windings connected together, and all secondary windings plus the screen connected together.

Specifying the Measurement
During the test, a dc voltage is ramped up across the protection device (MOV) under test and the current is monitored. When the desired current flows, the test stops and the measured result is the break-down voltage. If the voltage is within the desired limits, the test is a PASS. If the voltage is outside the desired limits, or if no breakdown is detected when the maximum voltage is reached, the test is a FAIL.

The voltage will ramp to the specified maximum plus 50V. In programming the AT5600 you may select the voltage (from 100V to 7kVdc), the current trip level (10μA to 3mA), and the ramp up times (1 to 2 sec), all to suit the specification of the transformer under test.
2.45 WATT - Wattage

Where Used
The Wattage test is a measure of the input power required to energize a transformer at no load. A Wattage test is an excellent check on the magnetic quality of the iron core and the magnetic joints and would typically be used with iron core transformers with an operating frequency of around 50Hz.

Measurement Conditions
During the Wattage test, a constant, user specified ac voltage is applied across the winding in question. All other windings are held open circuit during this test.
The AT5600 measures the voltage across and current through the winding. The Wattage is the product of the in-phase components of the current and voltage. If, in the program, the WATT test follows either a VOC or MAGI test which has the same test conditions (voltage and frequency), and is applied to the same winding, then the measurement results from the previous tests can be re-used, saving program execution time. The test signal can have a frequency in the range 20Hz to 1.5KHz, and an amplitude from 1V to 270V.
3. Examples of Test Criteria for Different Transformer Types

3.0 Constructing a Test Program

The test program for a particular transformer can be downloaded from a PC compatible computer using either the Editor and Server Software.

In most programs, it is better to perform a resistance test on each winding first, as this will allow the continuity checks to verify the fixture wiring as soon as possible. Following this, tests can be placed in any order required.

However, for some transformers with high permeability cores, it is possible for the resistance test to leave the cores with residual magnetism, which will cause a subsequent inductance test to measure a value that is out of tolerance. In such cases, it is best to perform the inductance test first. Alternatively, perform a turns ratio test after the resistance test - this will demagnetize the core before the inductance test.

When a new transformer type is being tested, it is better initially to set up the AT SERIES to produce a full report for each test.

After enough transformers have been tested to ensure that sensible limit values have been programmed for each test, then the report format can be changed to ‘failures only’ which is the normal report format in a production situation.
3.1 Using the AT Series Editor Software to create test programs

The AT Editor software’s function is to provide an easy transformer test programming environment.

Communications must be set-up first to allow the PC to communicate with the AT via USB (AT5600 only) or RS232 leads supplied. External sources allow the user to set-up high voltage and current applications when using the AC Interface Fixture.
The screen shot below shows the ability to draw the schematic by adding windings, core connections and screen connections. Right click the mouse on any of the winding numbers and drag the connection to any of the 20-nodes available.
Program test parameters from a choice of individual tests (as shown in section 2),
To add these, just double click the required test from the test listing on the right-hand side.
Set your signal parameters and run your individual test by clicking the measure button or click OK to save the test in the program listing as shown below.
Give the fixture ID a name by clicking Program and then Options. Batch processing elements are also available here for use with the Server results storage software.

Once your program is finished you can download the program listing to the AT, compensate your test fixture and then run the entire program from the 'Tester' menu shown below.

Other features include the ability to edit tests, insert new tests and delete tests from a program listing.

The AT series Editor software operates both on the AT5600 ATi and the AT3600 providing a step-by-step programming system that starts from a simple schematic of the transformer.

There are in excess of 34 tests to choose from on the ATi and more than 38 tests to choose from on the AT3600 / AT5600. Single tests or entire programs can be run from the Editor or downloaded to the AT and run from the instrument.

Fixture compensation can also be selected before running the test, from the instrument or from the Editor software.
3.2 Testing Line frequency transformers

This transformer is tested using a plug-in fixture.

Although this transformer uses only 9 terminals, the fixture has all 10 terminals connected so that the fixture can be used with any other transformer designed on the same bobbin. The fixtures program describes the relationship between the terminal name on the plug-in socket and the AT SERIES node that it has been wired to.

It allows the test program that is written for the transformer, and all test results, to refer to the transformer terminal names.
Recommended measurements for line frequency transformers

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistances</td>
<td>To ensure correct wire size has been used and correct tension during winding. Checks that transformer properly installed in test fixture</td>
</tr>
<tr>
<td>Magnetizing Current</td>
<td>Checks for correct core material and core construction. Ensures that operating on correct point on B-H curve.</td>
</tr>
<tr>
<td>Open Circuit Voltages</td>
<td>Open circuit voltage tests confirm that windings have correct turns and have correct phasing</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>Only required on transformers used in patient contact in medical applications</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>Checks isolation between windings</td>
</tr>
<tr>
<td>Hi-Pot</td>
<td>Checks safety isolation primaries to secondaries (and to core if required)</td>
</tr>
</tbody>
</table>
3.3 Testing Miniature line frequency bobbin wound transformers

This miniature transformer is tested in a very similar way to the line frequency transformer described in Section 3.2, with the following important additions:

1. Insulation tests are added to check the insulation from primary to the safety screen and to the core.

2. The primary of this miniature transformer consists of a large number of turns of very fine gauge wire. Such a winding can be subject to premature breakdown in the field due to failure of the thin enamel coating between parts of the winding. The likelihood of field breakdown has been reduced by performing an inter-turn stress test on the transformer.
**Recommended measurements for line frequency transformers**

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistances</td>
<td>To ensure correct wire size has been used and correct tension during winding. Checks that transformer properly installed in test fixture</td>
</tr>
<tr>
<td>Magnetizing Current and Open Circuit Voltages</td>
<td>Checks for correct core material and core construction. Ensures that operating on correct point on B-H curve. Open circuit voltage tests confirm that windings have correct turns and have correct phasing</td>
</tr>
<tr>
<td>Stress</td>
<td>Checks for weakness of interturn insulation</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>Only required on transformers used in patient contact in medical applications</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>Checks isolation between windings</td>
</tr>
<tr>
<td>Hi-Pot</td>
<td>Checks safety isolation. primaries to secondaries (and screen and core)</td>
</tr>
</tbody>
</table>
3.4 Testing Switched-Mode Power Supply Transformers

Part Number L1492
Recommend measurements for switched mode transformers

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistance</td>
<td>To ensure that correct wire or foil has been used during winding. Checks that transformer has been properly installed in test fixture</td>
</tr>
<tr>
<td>Inductance</td>
<td>Ensures that winding has correct primary turns, and the proper air gap or grade of magnetic material. For transformers without air gaps it ensures that core faces have been cleaned and are sufficiently tight.</td>
</tr>
<tr>
<td>Q factor</td>
<td>Can be used to detect shorted turns in wires or foils that have occurred during assembly.</td>
</tr>
<tr>
<td>Turns Ratio and Phasing</td>
<td>Checks that transformer has correct turns on every winding. Verifies that polarity of each winding is correct</td>
</tr>
<tr>
<td>Leakage Inductance</td>
<td>Checks that windings have been correctly positioned on bobbin</td>
</tr>
<tr>
<td>Interwinding Capacitance</td>
<td>Checks that proper spacing has been achieved between windings</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>Required for SMPS transformers used in medical applications</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>Checks non-safety insulation between windings and screens</td>
</tr>
<tr>
<td>Hi-Pot</td>
<td>Checks safety isolation. Primaries to secondaries (and to safety screen and core)</td>
</tr>
</tbody>
</table>
3.5 Pulse Transformer

This transformer is tested using a plug-in fixture. The fixture is constructed to accommodate 5 of the pulse transformers at once and the program constructed to test all 5 in one test cycle.

The transformers are tested five at a time because the test specification demands a Hi-pot test of ten seconds duration. For this transformer, Hi-pot failures are very rare, so applying the Hi-pot voltage across all 5 transformers in parallel results in substantial time saving.
Recommended measurements for pulse transformers.

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistance</td>
<td>To ensure correct wire size has been used, and that the transformer is properly installed in fixture</td>
</tr>
<tr>
<td>Inductance</td>
<td>Ensures that winding has correct primary turns, and the correct magnetic material. Ensures that core faces have been properly cleaned before assembly</td>
</tr>
<tr>
<td>Turns Ratio and Phasing</td>
<td>Checks that the transformer has correct turns on all windings, and that polarity of the windings is correct</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>For checking insulation up to 850 Vdc</td>
</tr>
<tr>
<td>Hi-Pot</td>
<td>For checking insulation at higher voltages (e.g. 500V to 5kV rms)</td>
</tr>
</tbody>
</table>
3.6 Testing Audio Transformers

This transformer is designed for microphone matching, with the outputs either series or parallel connected to match impedances. The transformer is terminated with flying leads.

The fixture program allows the test program, and all the test results, to refer to the transformer terminal names, in this case the colour of the flying leads.
Recommended measurements for audio transformers

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistance</td>
<td>To ensure correct wire size has been used and that wire has not been over tensioned during winding. Checks connection to fixture.</td>
</tr>
<tr>
<td>Inductance, Q Factor</td>
<td>Checks for correct primary turns and proper core assembly. Confirms that the core is of the correct material and that no winding shorts have occurred during winding or assembly.</td>
</tr>
<tr>
<td>Turns Ratio and Phasing</td>
<td>Checks that all windings have correct turns and polarity.</td>
</tr>
<tr>
<td>Interwinding Capacitance</td>
<td>Checks that windings have been properly layered with correct tape thickness between windings.</td>
</tr>
<tr>
<td>Leakage Inductance</td>
<td>Checks that the windings have been correctly positioned on the bobbin.</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>Checks insulation e.g. between secondaries or primary to secondary for test voltages &lt; 850 V DC</td>
</tr>
</tbody>
</table>

**Note:**
This Audio transformer has a high permeability iron core. Inductance is the first test so that inductance is not influenced by any magnetization of the core that may occur due to resistance tests.
3.7 Current Transformers

When current passes through the primary of a current transformer, this current induces a magnetic field in the core. This magnetic field generates a current in the secondary, which flows through the secondary load (burden). Voltage appears across the secondary winding proportional to both the secondary current and the value of the load resistance.

The level of magnetic flux in the core depends on the secondary voltage, and the core should be checked at the highest working voltage that appears across the secondary. Measuring the magnetizing current that flows into the secondary when the secondary is energized at this voltage provides confirmation that the current transformer will operate at its rated burden or load.

Part Number CT1127
To determine the correct energization voltage for the secondary:

1) Calculate secondary current at maximum rated primary current

\[
\text{Secondary current} = \frac{\text{Primary Current}}{\text{Ratio}} = \frac{100 \text{A}}{1000} = 100 \text{mA}
\]

2) Calculate rms voltage across secondary at this secondary current using maximum burden or maximum specified load resistance.

\[
V_{\text{secy}} = \frac{\text{Burden}}{\text{Secondary Current}} = \frac{5 \text{VA}}{100 \text{mA}} = 50 V_{\text{rms}}
\]

or

\[
V_{\text{secy}} = \text{Secondary Current} \times \text{Max Load Resistance}
\]

\[
= 100 \text{mA} \times 500 \Omega = 50 V_{\text{rms}}
\]

Recommended Measurements for Current Transformers

<table>
<thead>
<tr>
<th>Test</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Winding Resistance and Primary Winding Resistance if wound primary</td>
<td>To ensure correct wire size has been used. Checks that transformer is properly installed in fixture.</td>
</tr>
<tr>
<td>Magnetizing Current</td>
<td>Checks for correct core material. Ensures that core is operating at correct point on B-H curve</td>
</tr>
<tr>
<td>Turns Ratio</td>
<td>Checks that CT ratio is correct</td>
</tr>
<tr>
<td>Insulation Resistance or Hi-Pot</td>
<td>Checks isolation primary to secondary, particularly with wound primaries</td>
</tr>
</tbody>
</table>
Fixture

This current transformer is one of a range with ratios as high as 10,000:1.

The fixture was therefore constructed to incorporate a test primary consisting of a loop of 10 turns of insulated wire with a miniature 10 pin circular connector that could fit through that centre of the current transformer.

With only a one turn primary, the primary voltage measured during a turns ratio test will be very small on high ratio transformers.

A 10-turn primary increases this voltage and achieves much better accuracy.
3.8 DC Chokes

Multi winding chokes are becoming increasingly popular in multi-output switched mode power supplies, offering enhanced regulation characteristics compared to single chokes. Multi-winding chokes make good use of the versatile testing capability of the AT SERIES.

All dc chokes use low permeability cores, either powdered iron or ferrite cores with a substantial air gap. A low permeability is essential to prevent the core saturating with a large dc current.
<table>
<thead>
<tr>
<th>High Permeability</th>
<th>Low Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Inductance</td>
<td>Low Inductance</td>
</tr>
</tbody>
</table>

Inductance is a measure of the slope of the B-H curve. A core with high permeability can have a slope or inductance value with a wide tolerance. The low permeability of cores with an air gap or made of powered iron causes these cores to exhibit an inductance that can be specified within very tight limits.

It is essential during design testing to confirm that a dc choke exhibits the proper inductance at rated dc current. In production testing, however, dc chokes can be tested by checking the inductance without dc bias - specifying tight limits will verify that the core has the correct turns and therefore the correct slope, to give the required inductance at the specified dc current.
Recommended measurements for dc chokes.

<table>
<thead>
<tr>
<th>Test</th>
<th>Why</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Resistance</td>
<td>Checks correct wire size has been used</td>
</tr>
<tr>
<td>Inductance</td>
<td>Checks for correct turns, and correct permeability or air gap</td>
</tr>
<tr>
<td>Turns Ratio</td>
<td>Checks turns and phasing of all windings</td>
</tr>
<tr>
<td>(Multi-winding chokes)</td>
<td></td>
</tr>
<tr>
<td>Leakage Inductance (Multi-winding chokes)</td>
<td>Checks that winding have been correctly positioned on core or bobbin.</td>
</tr>
<tr>
<td>Insulation Resistance (Multi-winding chokes)</td>
<td>Checks working insulation between windings.</td>
</tr>
</tbody>
</table>