

Winding Resistance Measurements

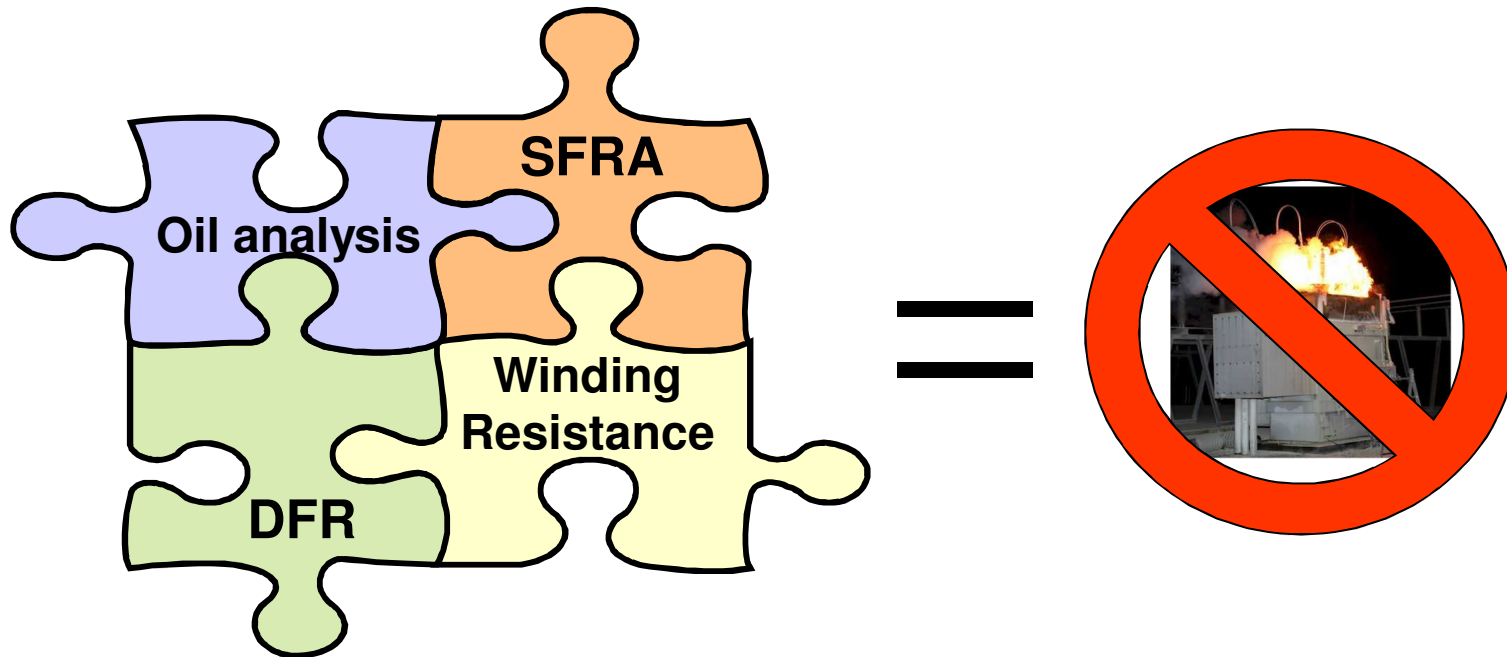
Megger MTO210



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Transformer Diagnostics

- Diagnostics is about collecting reliable information to make the correct decision
- Making the correct decisions saves money



Standards and recommendations

Winding resistance measurement (WRM) on power transformers is one of the most common transformer tests and covered in numerous international standards e.g.

- IEEE C57.12.90-2006, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE C62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus - Part 1: Oil Filled Power Transformers, Regulators, and Reactors (to be replaced by C57.152)

WRM – When

- Factory test
- Installation/commissioning
- Routine (Scheduled) Transformer Maintenance
- Unscheduled Maintenance/Troubleshooting
- Internal Transformer Inspections

WRM – Why Faults to be identified

- Poor connections
- Shorted turns
- Open turns
- Defective tap changers
- And more...



Power Components to test

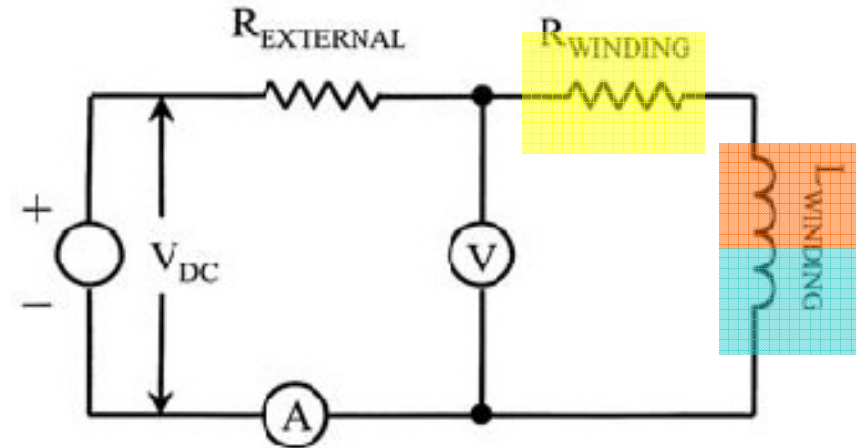
- Transformers
- Generators
- Electrical motors
- Cable splices
- Bus bar joints
- Welding joints
- Etc

WRM application and practices

WRM Basic theory

$$U = R \times I + \frac{d\phi}{dt} \quad \phi = \text{flux}$$

$$L = \frac{\phi}{I}$$



$$U = R \times i(t) + L(i, t) \times \frac{di(t)}{dt} + i(t) \times \frac{dL(i(t), t)}{dt}$$

Winding
resistance
×
current

Inductance ×
change of
current
(=0 if current is
constant)

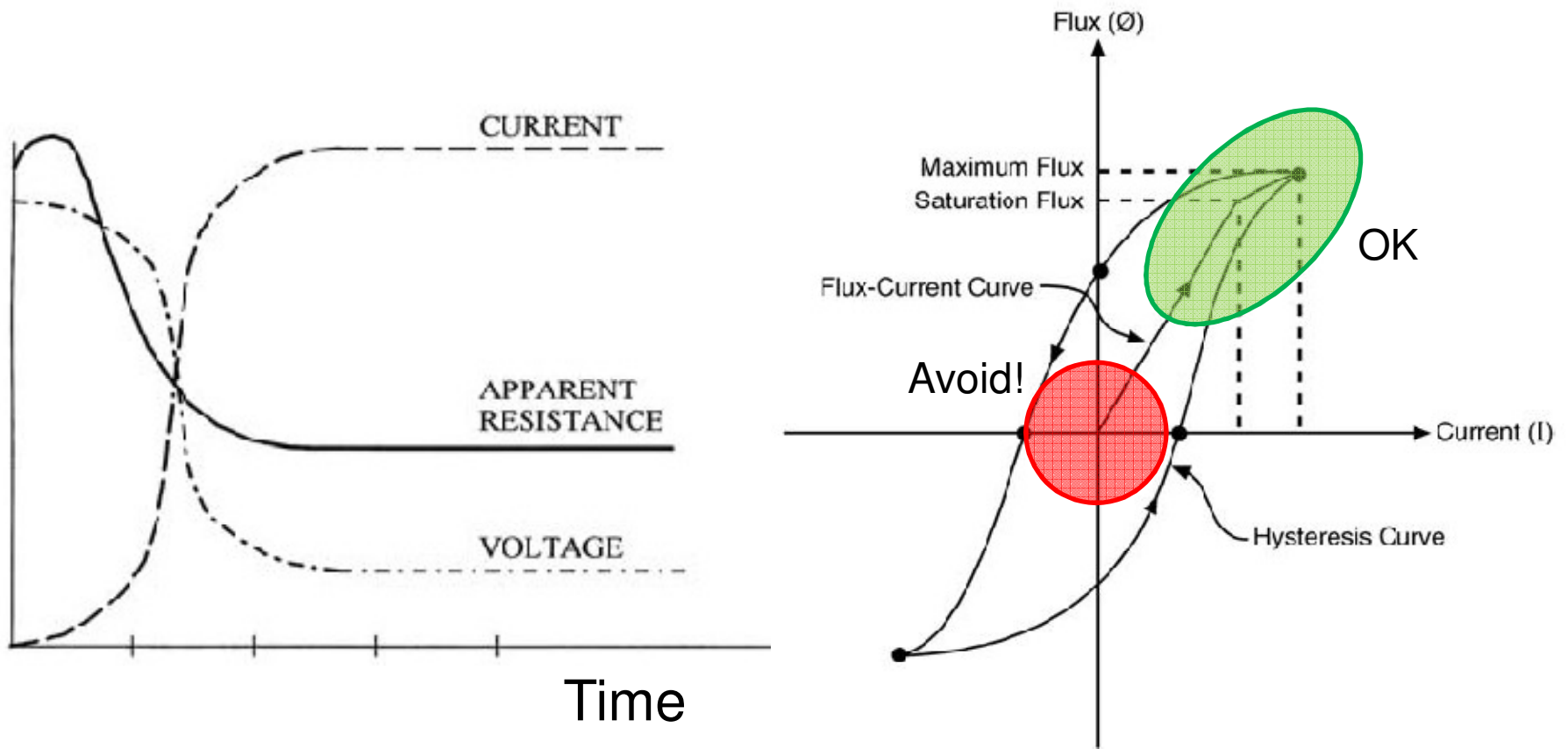
current × **change of
inductance.**
Inductance is a
function of **current
AND time**

Selecting Test Current Range

- Always try to saturate the core. This happens typically when the test current is about 1% of rated current
- Never exceed 10% of rated current. This could cause erroneous readings due to heating of the winding
- Typical test currents are 0.1-10% of rated current
- If test current is too low, measured resistance is not consistent (pending magnetic status before the test is started)

Tip: If MTO indicates input voltage overload, you have selected a test current > 10%. Select next current range and restart

Principal relationship between applied voltage, resistance and core saturation



Winding resistance measurement – How

- Decide if single or 2-ch measurement/current injection is appropriate
- Connect current and voltage measurement cables to the actual transformer winding(-s)
- Select test current
- Start test
- Wait for measurement results to stabilize
- When stable value, stop measurement/store result, discharging starts automatically
- Wait until discharging is finalized before disconnecting any cables!
- Next measurement...
- When finished - Demagnetize

Tap-changer Testing (on-load LTC)

- Connect to transformer and select test current
- Measure resistance for first tap and store results (use remote switch)
- Operate tap-changer. Watch for indication of open connection/interruption
 - MTO210 will begin flashing “Open Circuit” indicator but continue testing if open circuit detected for between 1mS and 10ms
 - If an open circuit is detected for greater than 10ms, “Open-Circuit” indicator will flash, MTO210 will shut down and discharge the test specimen.
- Measure/store results for second tap (use remote control)
- Operate tap-changer and measure next tap
- Etc until all taps are measured
- Export data for reporting

Interpretation of Measurements

- Comparing to original factory measurements
- Comparing to previous field measurements
- Comparing one phase to another

Industry/factory standard permits a maximum difference of 0.5% from the average of the three phase windings.

Field readings may vary more than this due to the many variables, in particular the problem of determining exact winding temperature. Suggested guidelines;

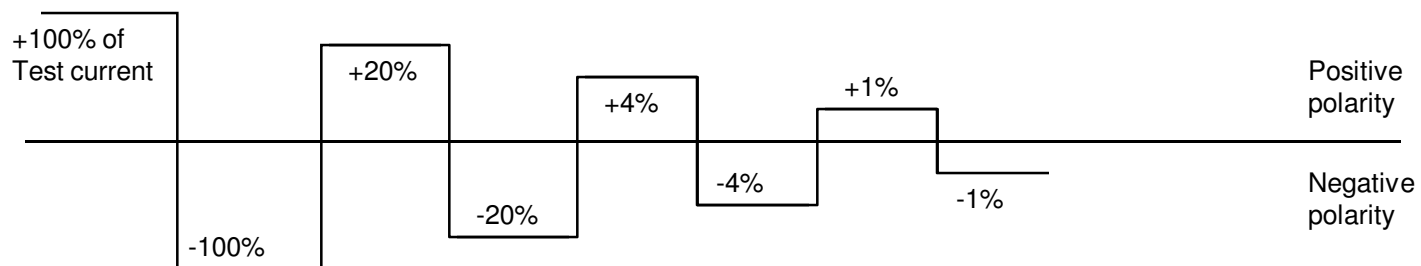
Absolute readings	Within 5%
Relative readings between windings	Within 1%

Temperature dependence

- Measured resistance is pending winding temperature
- Resistance correction:
 - $R(\text{initial})[1 + \alpha (T(\text{final}) - T(\text{initial}))]$, where $\alpha(\text{copper})$ is 0.0039 (0.39% per degree C)

Demagnetization

- MTO210 has the ability to demagnetize the transformer core
- Accomplished by switching the polarity of the DC current and then repeating the same procedure while decreasing the current level
- Only necessary to connect to one of the HV windings
- Important before SFRA testing
- Will be recommended in upcoming IEEE C57.102 (former IEEE 62) before reconnecting the transformer back in service (to avoid potentially dangerous in-rush currents)



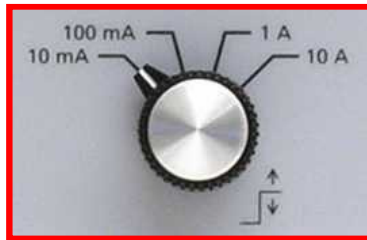
MTO210 – Key features

- Up to 10 A output current
- Up to 50 V output voltage
- 2-ch measurements and dual-winding test current injection
- Very fast discharge
- Automatic demagnetization capability
- Kelvin clamps/cables (option) for simplified hook-up
- Stand-alone operation
- Internal memory (2000 records)
- PowerDB reporting and data storage
- Tap-changer testing
- Enhanced safety features
 - Current cable safe-lock contacts
 - Safety interlock cables (option)
 - Warning strobe light (option)
 - Remote control switch (option)



MTO Overview

Maximum Test Current Setting, 0.01 to 10A



Output Current Selector

The selector switch is used to select the desired maximum test current.

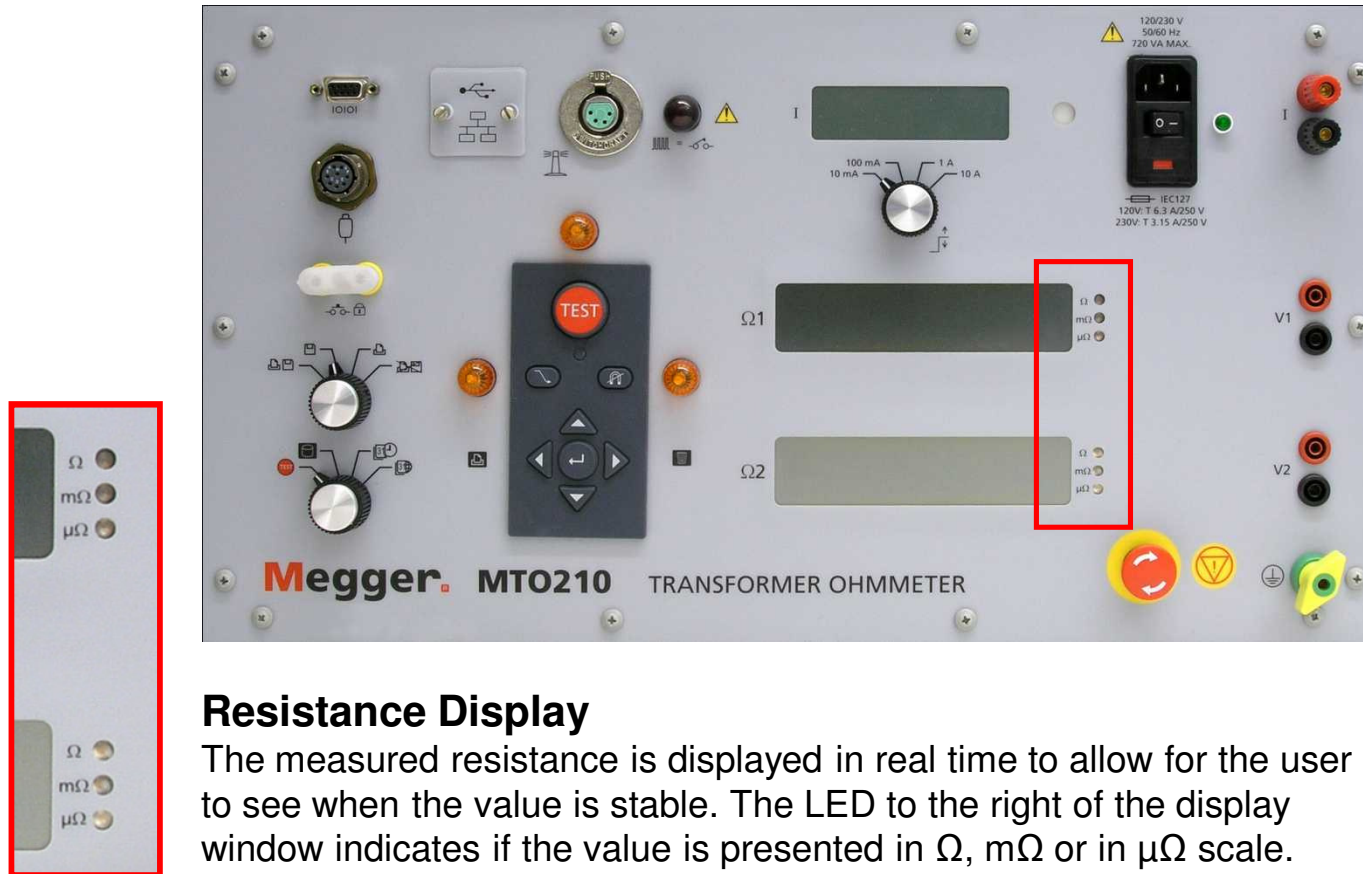


Output Current Terminals

These connections are used to connect to the transformer winding(s) for testing and demagnetization. The connection is capable of supplying up to 10 A current at up to 50 V output voltage

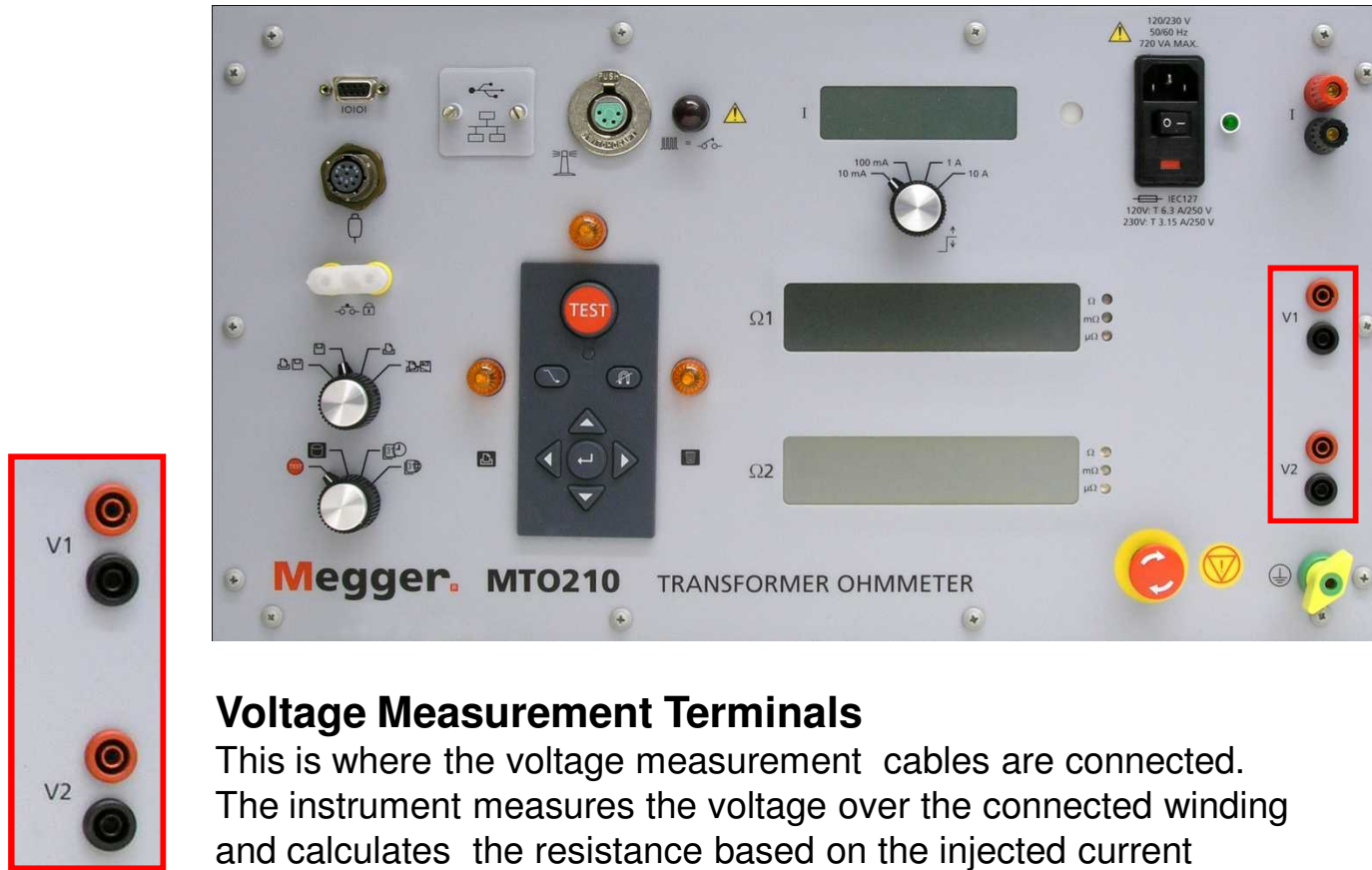
MTO Overview

Resistance display



MTO Overview

Voltage measurement terminals



MTO Overview

Start and stop test



Test button

The test button is used to start the test. When the resistance value is stable, press the test button again, the test is aborted and result will be stored in the memory.

The test indicator lamp is flashing when test current is flowing.

MTO Overview

Mode selector switch



Test mode
Instrument is ready for test



Date & Time mode
Set date and time



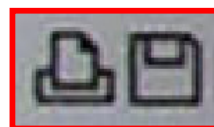
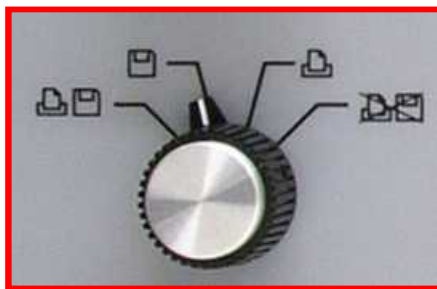
Storage review mode
Toggle between test results



Date format mode
Set date format

MTO Overview

Data print & Save selector switch



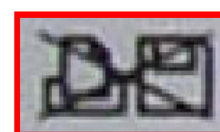
Print & Save mode



Print mode



Save mode

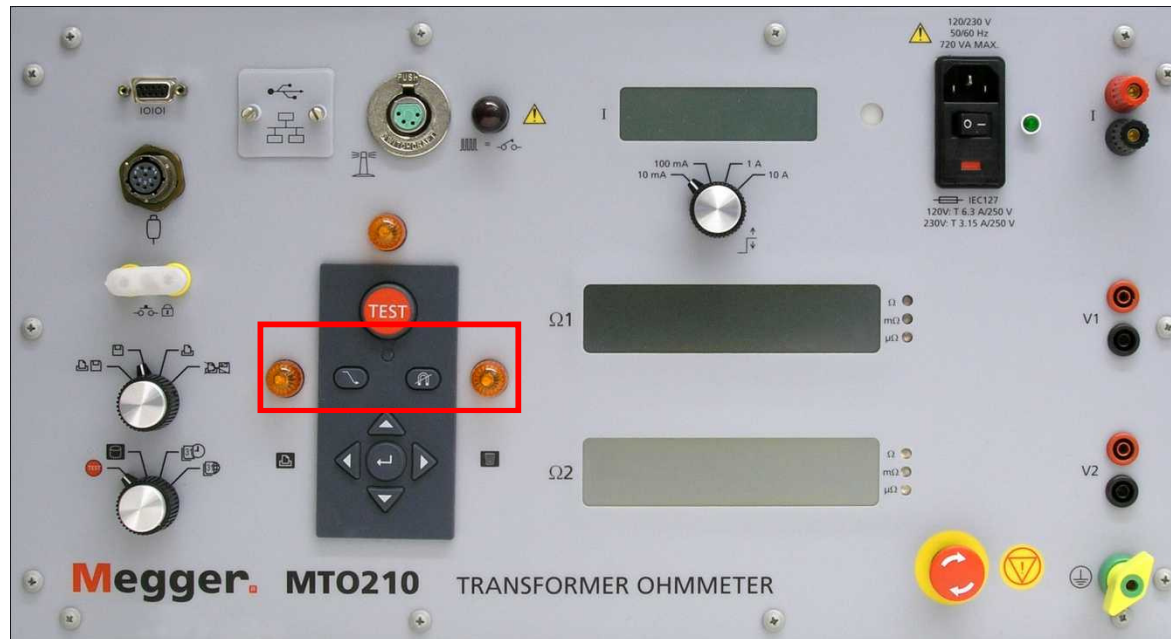


No save or print mode

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MTO Overview

Discharge and Demagnetization buttons



Discharge & Demagnetization buttons

The discharge button stops the test and discharges the test object without displaying/storing any result. The discharge lamp to the left illuminates during discharge process.

The demagnetization button starts the demagnetization cycle described in a separate slide. Indicator lamp to the right illuminates during this process.

Demagnetization progress is communicated in the display.

MTO Overview

Remote control function



Remote control

The remote control function allows for OLTC testing. Start the test by pushing the TEST button and wait until resistance values are stable. Press the remote control button to store the result for the tap step. Note that the current flow continues until the user stops the test. Operate the LTC to next step and press the remote button for every new step.



MTO Overview

Brake-before-make function



Brake-before-make indicator

The instrument detects an unexpected interruption in current flow and if the interrupt is longer than 10 ms, it will automatically turn off the current.

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MTO Overview

Beacon connector

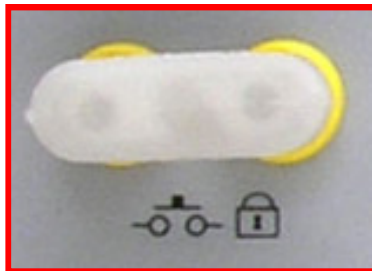


Beacon connector

An external flashing beacon can be connected. (Optional accessory)
The beacon illuminates when current is generated.

MTO Overview

Interlock connectors



Interlock connectors

This feature can be used when testing requires interlock mechanism on the transformer. The instrument aborts the test if interlock circuit opens.

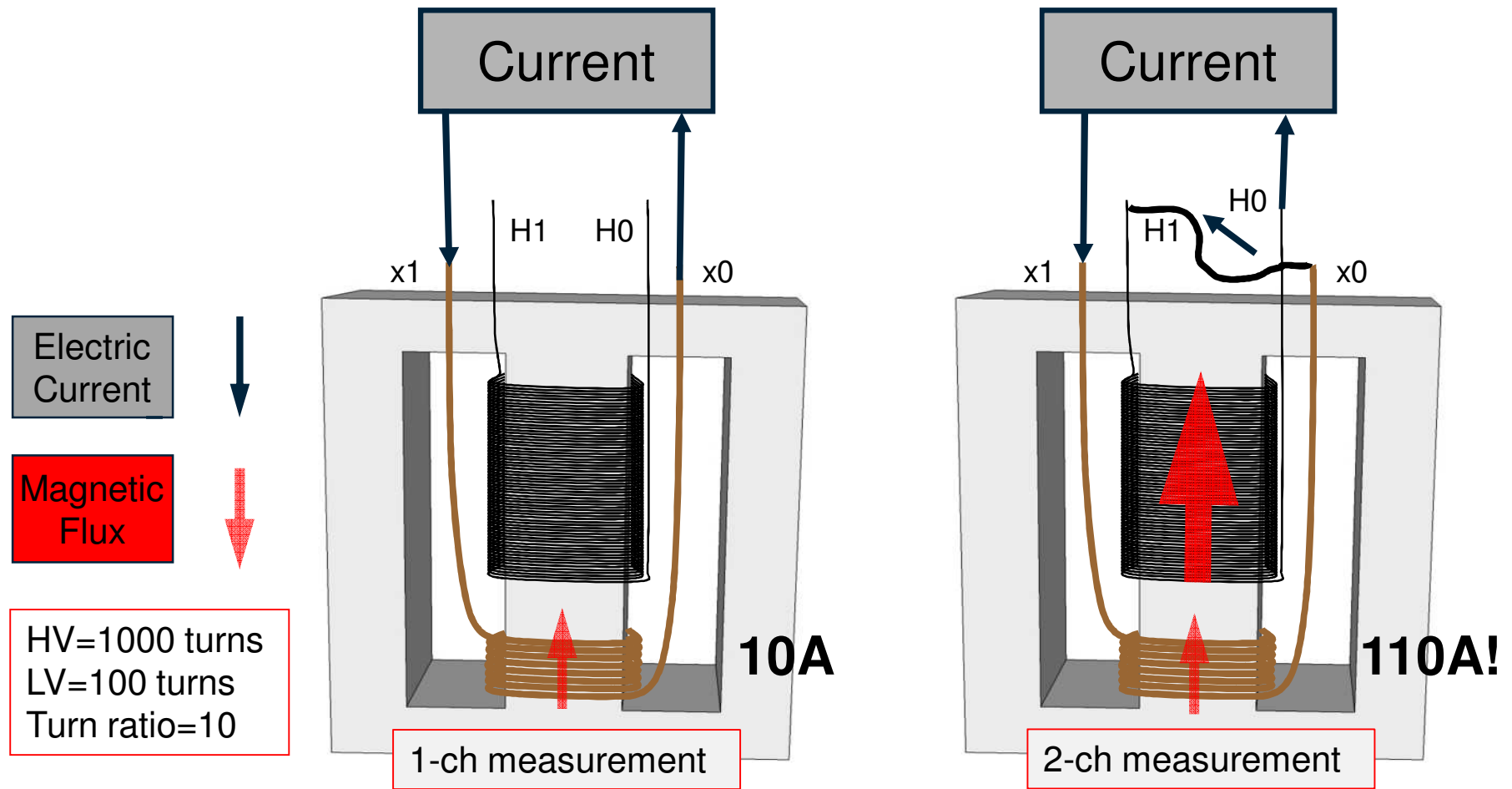
WRM field test guide

- Use a high accuracy dedicated winding resistance test set with sufficient compliance voltage and test current
- Ground the instrument!
- Before you start measurements – Make a safety check
- Measure HV side (for all tap positions if LTC is on HV side)
- Continue with LV side (for all tap positions if LTC is on LV side). Use dual injection technique if necessary to amplify test current
- Or use 2-ch and measure HV and LV simultaneously
- Never remove any cables before the transformer is fully discharged!
There is a lot of energy in a charged transformer!
- Demagnetize the core after test

Winding Resistance Measurements

2-ch measurement application examples

Increase magnetization and effective test current

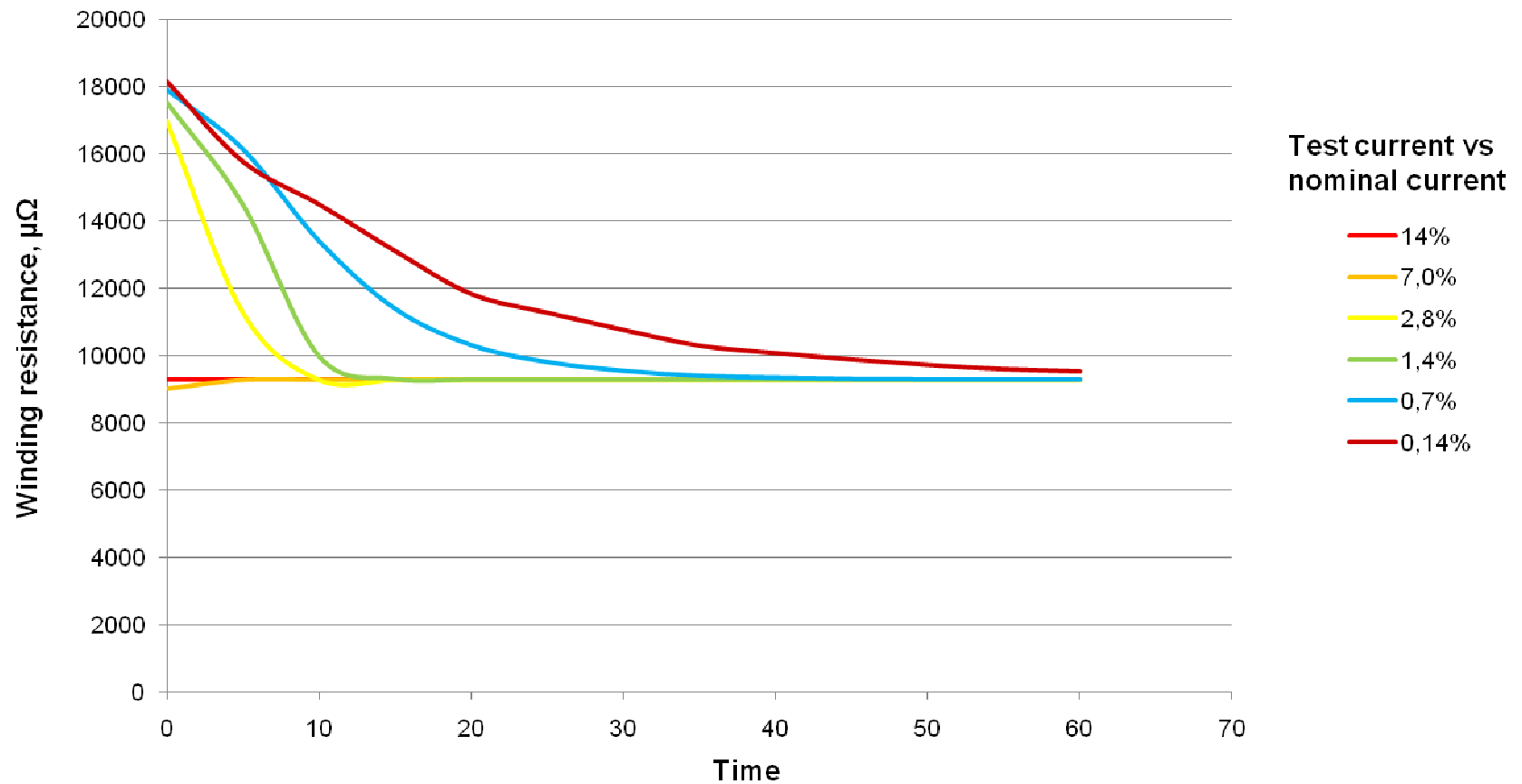


Magnetization increases by factor of turn-ratio

10A test current X 10 Turn ratio = **110 A** "effective test current" for the LV measurement!

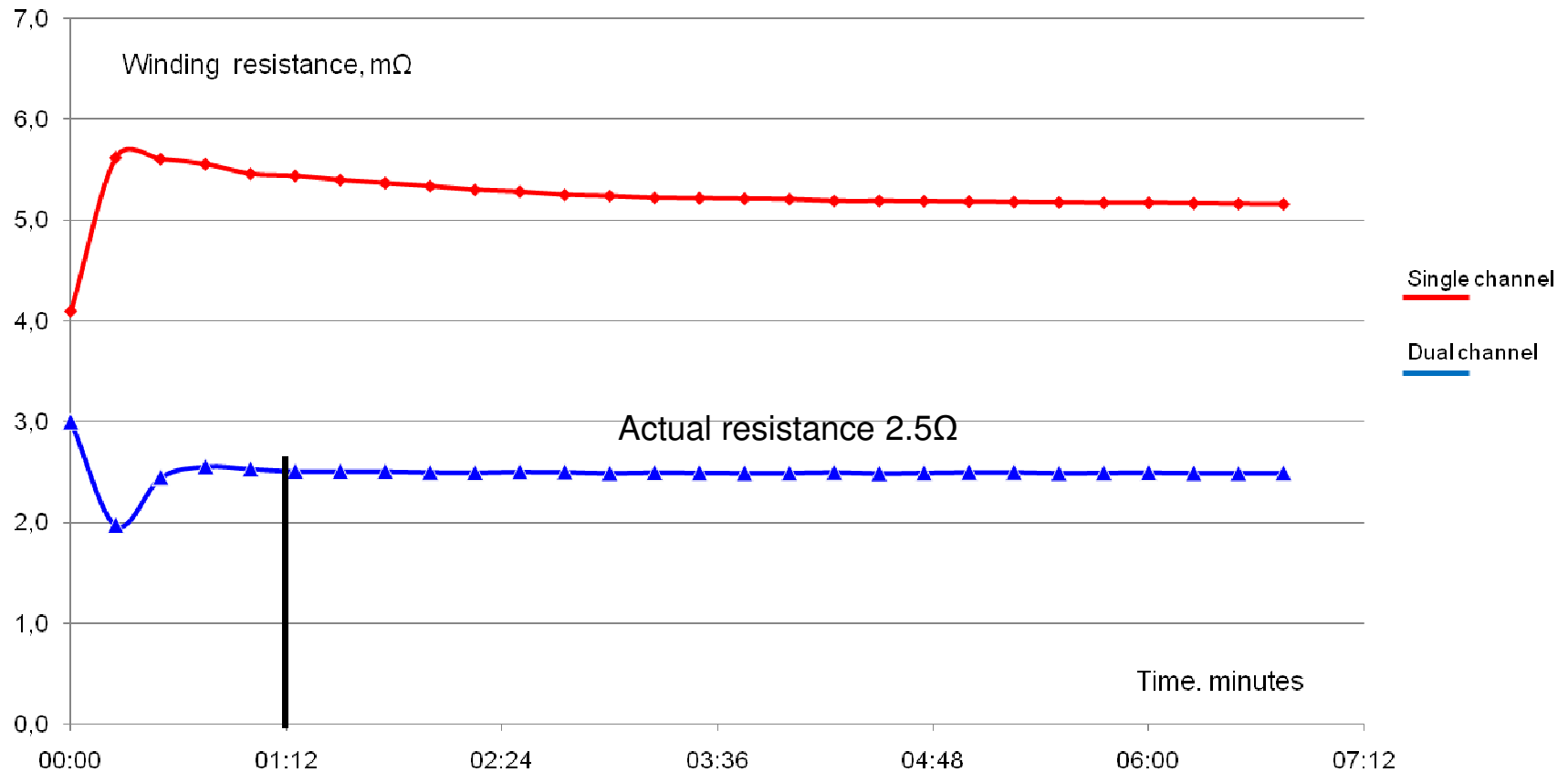
WRM - Delta configuration example, single-channel injection/measurement

Small demo transformer, 0.14 – 14% test current



WRM – LV delta measurement example

220 MVA YNd11, LV 1-3, 10A test current, 0.12% of rated current



Dual Channel Connection and Measurement

TABLE 1.

EXAMPLES ON TRANSFORMER CONNECTION SCHEMES
FOR INJECTING TEST CURRENT AND MEASURING TWO WINDINGS SIMULTANEOUSLY

Vector Group	Measurement setup						
	Current Connections			Meas ch 1		Meas ch 2	
	+ Current	Jumper	- Current	+	-	+	-
Dd0	H1	H3-X1	X3	H1	H3	X1	X3
	H2	H1-X2	X1	H2	H1	X2	X1
	H3	H2-X3	X2	H3	H2	X3	X2
Dyn7	H1	H3-X0	X1	H1	H3	X0	X1
	H2	H1-X0	X2	H2	H1	X0	X2
	H3	H2-X0	X3	H3	H2	X0	X3
Dyn1	H1	H3-X1	X0	H1	H3	X1	X0
	H2	H1-X2	X0	H2	H1	X2	X0
	H3	H2-X3	X0	H3	H2	X3	X0
YNyn0	H1	H0-X1	X0	H1	H0	X1	X0
	H2	H0-X2	X0	H2	H0	X2	X0
	H3	H0-X3	X0	H3	H0	X3	X0
Ynd1	H1	H0-X1	X2	H1	H0	X1	X2
	H2	H0-X2	X3	H2	H0	X2	X3
	H3	H0-X3	X1	H3	H0	X3	X1
Dy1	H1	H3-X1	X2	H1	H3	X3	X2
	H2	H1-X2	X3	H2	H1	X1	X3
	H3	H2-X3	X1	H3	H2	X2	X1
YNd7	H1	H0-X2	X1	H1	H0	X2	X1
	H2	H0-X3	X2	H2	H0	X3	X2
	H3	H0-X1	X3	H3	H0	X1	X3
Dyn5	H1	H2-X0	X1	H1	H2	X0	X1
	H2	H3-X0	X2	H2	H3	X0	X2
	H3	H1-X0	X3	H3	H1	X0	X3
Dy11	H1	H3-X1	X3	H1	H3	X1	X3
	H2	H1-X2	X1	H2	H1	X2	X1
	H3	H2-X3	X2	H3	H2	X3	X2
Dyn11	H1	H2-X1	X0	H1	H2	X1	X0
	H2	H3-X2	X0	H2	H3	X2	X0
	H3	H1-X3	X0	H3	H1	X3	X0